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# THE ASTROPHYSICAL JOURNAL

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*Founded in 1895 by* GEORGE E. HALE *and* JAMES E. KEELER

*Edited by*

HENRY G. GALE
Ryerson Physical Laboratory of the University of Chicago

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Yerkes Observatory of the University of Chicago

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## SEPTEMBER 1935

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THE ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY AND ASTRONOMICAL PHYSICS

VOLUME 82 SEPTEMBER 1935 NUMBER 2

# THE VISUAL REGION OF THE SPECTRA OF EARLY-TYPE STARS

ROY K. MARSHALL

ABSTRACT

Twenty-one films and seven plates of eight stars ranging in spectral class from B2 to A2 were measured for wave-lengths. The spectrograms were made with an auto-collimating grating spectrograph and the region in good focus extends from 4713 to 6678 A. About 56 per cent of the 357 tabulated wave-lengths are considered to be satisfactorily identified.

The spectrograms used in this work were obtained with the auto-collimating spectrograph of the Yerkes Observatory attached to the 69-inch reflector of the Perkins Observatory; the grating was used in the region between H$\alpha$ and $H\beta$, but a few of the stronger lines lying immediately outside this region were also found to be measurable. For a considerable portion of the material on hand, thin plates, bent to fit the focal curve, had been used, but the spectra photographed on films were so superior and of such excellent definition that the material given here depends only on the films (see Table I), although measures of seven plates of $\alpha$ Cygni were used to check the wave-lengths for that star. The spectra of $\alpha$ And and $\epsilon$ U Ma were included because of their peculiar character. The identifications should be considered in connection with the work by Morgan,[1] Struve,[2] and the writer.[3]

[1] *Pub. Yerkes Obs.*, **7**, Part III, 1935.

[2] *Ap. J.*, **74**, 225, 1931.

[3] *Pub. Michigan Obs.*, **5**, 137, 1934.

The results are presented in Table II. Only the lines which persisted on more than one film, or were conspicuously strong on a single film, have been retained; only a few of the tabulated lines should prove to be unreal. The atmospheric lines (of which all in the *Revision* of Rowland's table of intensity greater than zero were accounted for) have been sorted out as well as possible, but it is likely that a few lines of telluric origin have been retained. The approximate wave-lengths appear in the first column, and the values of the

TABLE I

| Star | Spectrum | No. Films |
|---|---|---|
| $\gamma$ Orionis | $B_2$ | 1 |
| $\beta$ Tauri | B8 | 2 |
| $\beta$ Orionis | B8p | 3 |
| $\alpha$ Canis Majoris | Ao | 3 |
| $\alpha$ Lyrae | Ao | 3 |
| $\alpha$ Andromedae | Aop | 2 |
| $\epsilon$ Ursae Majoris | Aop | 2 |
| $\alpha$ Cygni | $A_2p$ | 5 |

measured wave-lengths and estimated intensities in the several stars are given in the next eight columns. Of the 357 lines in the table, the identifications for about 56 per cent may be considered fairly satisfactory. Minor contributors, or doubtful identifications, have been inclosed in brackets. The sources for the laboratory wave-lengths are those commonly used, and may be found listed for the most part in Miss Moore's *Multiplet Table of Astrophysical Interest.*[4] Reference was made also to Mitchell's flash spectrum,[5] and to Dunham's spectrum of *a* Persei.[6]

I wish to express my thanks to Messrs. Roach, Hynek, and Van Arnam, who obtained the spectrograms; to Dr. Morgan, who suggested the method of obtaining the reduction-curve; and to Dr. Struve, who suggested and encouraged the measurement of these spectrograms at the Yerkes Observatory.

February 20, 1935

[4] Princeton, N.J., 1933.

[5] *Ap. J.*, **71**, 1, 1930.

[6] *Contr. Princeton Univ. Obs.*, No. 9, 1929.

TABLE II

| Approx. Wave-Length | γ Ori (B2) | β Tau (B8) | β Ori (B8p) | α CMa (Ao) | α Lyr (Ao) | α And (Aop) | ε UMa (Aop) | α Cyg (A2p) | Identifications |
|---|---|---|---|---|---|---|---|---|---|
| 4713 | | | 3.20(8) | | | | | | *He* I 3.14(3); *He* I 3.37(1) |
| 4788 | | | 8.76(2) | | | | | | |
| 4805 | | | | | | | | 5.14(6) | *Ti* II 5.10(2) |
| 4812 | | | | | | | | 2.20(3) | *Cr* II 2.36(2) |
| 4815 | | | 5.62(3) | | | | | | *S* II 5.52(9) |
| 4824 | | 4.33(4) | 4.73(2) | 4.61(3) | 4.18(3) | | 4.18(4) | 4.44(8) | *Cr* II 4.14(10) |
| 4836 | | | | | | | 6.26(4) | 6.35(2) | *Cr* II 6.24(2) |
| 4838 | | | 8.46(2) | | | | | | |
| 4848 | | | | | | | 8.48(3) | 8.30(6) | *Cr* II 8.25(8) |
| 4856 | | | | | | | | 6.21(2) | *Cr* II 6.20(1) |
| 4861 | 1.33(15) | 1.30(20) | 1.35(17) | 1.39(30) | 1.33(30) | 1.21(20) | 1.24(30) | 1.30(20) | *Hβ* 1.33; *Cr* II 0.22(1) |
| 4864 | | | | | | | | 4.49(2) | *Cr* II 4.33(3); |
| 4871 | | | | 1.19(2) | 0.94(2) | | | 1.25(2) | *Fe* I 1.32(25) |
| 4876 | | | | | 6.52(2) | | 6.31(3) | 6.63(3) | *Cr* II 6.41(2) |
| 4884 | | | | | | | 4.43(2) | 4.62(3) | *Cr* II 4.60(1) |
| 4885 | | | | | | | 5.72(3) | | |
| 4891 | | | | 1.34(3) | | | 1.49(3) | | *Fe* I 1.49(50); *Fe* I 0.76(25) |
| 4896 | | | | | 6.99(1) | | | 6.96(2) | |
| 4898 | | | | | 8.68(1) | | | 8.94(1) | *Al* II 8.76(5); *Al* II 8.52(2); *Al* II 9.64(3) |
| 4901 | | | | | 1.11(1) | | | 1.50(1) | *Cr* II 1.62(1) |
| 4902 | | | | 2.58(1) | 2.89(1) | | 2.60(3) | 2.83(2) | *Al* II 2.77(5) |
| 4905 | | | | | 5.11(2) | | | | |
| 4911 | | | | | | | 1.19(3) | 1.43(2) | [*Ti* II 1.19(0)] |
| 4917 | | | 7.31(1) | | 7.17(1) | 7.34(1) | | 7.00(1) | *S* II 7.21(5) |
| 4920 | | | | | | | 0.76(3) | | *Fe* I 0.50(60) |
| 4921 | 1.93(10) | 1.95(3) | 1.85(5) | 1.74(2) | | 2.00(3) | | | *He* I 1.93(4); |
| 4923 | | | 3.86(4) | 3.95(4) | 3.91(5) | | 4.06(4) | 4.11(10) | *Fe* II 3.92(10); *S* II 4.04(5) |
| 4927 | | | | 7.73(1) | | | 7.80(2) | 8.05(1) | |
| 4932 | | | | | | | 2.56(2) | 2.68(2) | |
| 4933 | | | | 3.85(2) | | | 3.99(2) | | *Ba* II 4.10 (700) |

TABLE II—*Continued*

| Approx. Wave-Length | γ Ori (B2) | β Tau (B8) | β Ori (B8p) | α CMa (Ao) | α Lyr (Ao) | α And (Aop) | ε UMa (Aop) | α Cyg (A2p) | Identifications |
|---|---|---|---|---|---|---|---|---|---|
| 4945 | 5.77(2) | ..... | ..... | 5.58(2) | 5.83(1) | ..... | ..... | ..... | [*Ni* I 6.04(3); *Ni* I 5.45(2)] |
| 4949 | ..... | ..... | ..... | ..... | 9.35(1) | ..... | 9.12(2) | 9.28(2) | ..... |
| 4952 | ..... | ..... | ..... | ..... | 2.29(1) | ..... | 2.29(2) | 2.20(2) | [*Ni* I 2.33(1n); *Fe* I 2.65(1n)] |
| 4954 | ..... | ..... | ..... | ..... | 3.82(2) | ..... | 4.28(2) | ..... | ..... |
| 4957 | ..... | ..... | ..... | 7.63(3) | 7.50(2) | ..... | 7.84(4) | 8.06(2) | *Fe* I 7.62(60); *Fe* I 7.31(20) |
| 4984 | ..... | ..... | 4.63(2) | ..... | ..... | ..... | 4.78(2) | 4.86(2) | [*Fe* I 5.27(7); *Fe* I 5.54(7); *Fe* I 3.85(6n)] |
| 4991 | ..... | ..... | ..... | 1.25(2) | ..... | ..... | 1.35(3) | 0.92(2) | *Ti* I 1.07(50); *Fe* I .29(2) |
| 4993 | ..... | ..... | 3.39(2) | ..... | ..... | ..... | ..... | 3.63(2) | *S* II 3.46(3); *Fe* I 4.13(8); *S* II 1.90(5) |
| 4997 | ..... | ..... | ..... | ..... | ..... | ..... | 7.14(2) | 7.42(2) | ..... |
| 4999 | ..... | ..... | ..... | 9.53(2) | ..... | ..... | 9.39(2) | ..... | *Ti* I 9.51(45) |
| 5001 | 1.36(5) | ..... | 1.97(2) | 1.72(2) | ..... | 1.73(2) | 2.00(3) | 2.02(3) | *N* II 1.47(8); *N* II 1.13(7); *Fe* I 1.86(12); *Al* II 0.97(3) |
| 5006 | ..... | ..... | ..... | 6.93(2) | ..... | ..... | 6.69(2) | ..... | ..... |
| 5009 | 9.90(2) | ..... | 9.36(2) | 9.93(3) | ..... | ..... | ..... | 9.40(2) | *S* II 9.55(5) |
| 5014 | ..... | ..... | ..... | 4.22(2) | ..... | ..... | ..... | ..... | *S* II 4.08(6) |
| 5015 | 5.66(8) | ..... | 5.64(5) | ..... | ..... | ..... | 5.59(2) | 5.73(2) | *He* I 5.68(6); *Fe* I 4.94(10) |
| 5017 | ..... | ..... | ..... | 7.79(2) | ..... | ..... | ..... | ..... | *Ni* I 7.59(10) |
| 5018 | ..... | 8.27(2) | 8.60(5) | 8.34(5) | 8.43(5) | 8.37(3) | 8.61(5) | 8.40(10) | *Fe* II 8.44(8) |
| 5022 | ..... | ..... | 2.26(2) | 2.17(2) | 2.38(2) | ..... | 2.24(3) | 2.18(2) | *Fe* I 2.24(6) |
| 5030 | ..... | ..... | ..... | ..... | ..... | 0.28(2) | ..... | 0.31(2) | ..... |
| 5032 | ..... | ..... | 2.54(2) | ..... | ..... | ..... | ..... | ..... | *S* II 2.42(7) |
| 5035 | ..... | ..... | 5.07(2) | 5.75(2) | 5.59(2) | ..... | ..... | 5.77(2) | *Ni* I 5.98(3N) |
| 5037 | ..... | ..... | 7.67(2) | ..... | ..... | ..... | 7.85(2) | 7.56(2) | ..... |
| 5041 | ..... | 0.70(2) | 1.02(4) | 1.06(3) | 0.90(2) | ..... | 1.27(3) | 1.02(3) | *Si* II 1.06(8); *Fe* I 1.07(7); *Fe* I 1.76(10) |
| 5043 | ..... | ..... | 3.99(3) | ..... | ..... | 3.88(2) | ..... | ..... | ..... |
| 5044 | ..... | ..... | ..... | ..... | 4.33(2) | ..... | ..... | 4.59(2) | ..... |
| 5047 | ..... | ..... | ..... | ..... | ..... | ..... | 7.22(2) | 7.00(2) | ..... |
| 5048 | 7.95(4) | 8.03(3) | 7.76(3) | 8.04(2) | 8.18(2) | 8.08(3) | 7.92(2) | ..... | *He* I 7.74(2) |
| 5052 | ..... | ..... | ..... | 2.46(2) | 2.22(2) | ..... | ..... | 2.50(2) | ..... |
| 5056 | ..... | 6.15(4) | 6.13(5) | 5.99(4) | 6.16(2) | 5.90(5) | ..... | 6.02(5) | *Si* II 6.02(10); *Si* II 6.35(2) |

TABLE II—*Continued*

| Approx. Wave-Length | γ Ori (B2) | β Tau (B8) | β Ori (B8p) | α CMa (A0) | α Lyr (A0) | α And (A0p) | ε UMa (A0p) | α Cyg (A2p) | Identifications |
|---|---|---|---|---|---|---|---|---|---|
| 5061 | | | 1.81(2) | | 1.88(2) | | 1.68(2) | 1.77(2) | |
| 5066 | | | | | 6.66(2) | | | 6.90(2) | |
| 5068 | | | | | 8.87(1) | 8.84(3) | | 8.96(2) | *Fe* I 8.77(10); *Ti* II 9.12 (1) |
| 5071 | | 1.68(2) | | | 1.36(2) | | 1.40(2) | 1.64(2) | |
| 5073 | 4.15(3) | | 3.74(2) | | 3.67(2) | | 3.98(2) | | *N* II 3.60(3) |
| 5076 | 6.00(3) | | | | 6.33(1) | | 5.92(3) | 6.02(2) | *N* II 6.50(0) |
| 5082 | | | | | | | 2.49(2) | 2.49(2) | *Ni* I 2.35(4) |
| 5093 | | | | 3.43(2) | | | 3.78(3) | 3.69(2) | *Fe* I 3.34(7); *Al* II 3.65(2) |
| 5097 | | | | 7.14(2) | 7.46(2) | 7.06(2) | 7.26(3) | 7.30(2) | *Fe* I 7.00(6); *Ni* I 6.87(2); *Cr* II 7.41 (pred) |
| 5100 | | 0.29(2) | | 0.33(2) | | 0.96(2) | 0.76(3) | 0.88(3) | *Ni* I 9.94(10); *Al* II 0.34(1) |
| 5127 | 7.51(4) | | | | | | | | |
| 5128 | | 8.91(2) | | 9.10(2) | 9.08(2) | | | 8.73(2) | *Ti* II 9.17(1); *Ni* I 9.38(5) |
| 5133 | | | | 3.14(2) | 2.95(2) | | 3.30(2) | 2.90(2) | *Fe* I 3.69(20n) |
| 5136 | | | | 6.89(2) | 6.64(2) | | 7.05(2) | 6.67(2) | *Fe* I 7.38(6n); *Ni* I 7.08(8) |
| 5138 | | | | 8.88(2) | | 8.74(2) | | | |
| 5141 | | 1.81(2) | | | 2.11(2) | | | | |
| 5145 | | | | | | 5.12(2) | 5.42(2) | 5.03(2) | |
| 5149 | | | | | 9.27(2) | 9.59(3) | 9.47(4) | 9.36(2) | |
| 5153 | | | | | | | 3.75(5) | 3.35(2) | *Cr* II 3.59 (pred) |
| 5157 | | | | | | | 7.87(3) | | |
| 5160 | | | 0.42(1) | | | | 0.79(3) | 0.90(2) | |
| 5167 | | 7.96(2) | | 7.23(3) | 7.28(3) | | 7.26(2) | | *Fe* I 7.49(40); *Mg* I 7.32(8) |
| 5168 | | | 8.93(8) | 9.07(4) | 8.84(5) | 8.97(3) | 8.95(3) | 9.04(10) | *Fe* II 9.03(8); |
| 5172 | | | 2.99(2) | 2.53(3) | 2.62(4) | 3.10(2) | 2.59(3) | 2.63(3) | *Mg* I 2.70(9); *Fe* I 1.60(20) |
| 5177 | | | | 7.05(2) | 6.93(2) | 7.28(4) | 7.19(3) | 7.28(2) | |
| 5179 | | | | | 9.82(2) | | | 9.64(2) | |
| 5180 | | | | 0.81(2) | | | | 0.90(2) | |
| 5183 | | | | 3.67(4) | 3.61(5) | | 3.64(3) | 3.65(3) | *Mg* I 3.67(10) |
| 5186 | | | | 6.19(2) | | | 6.13(2) | 5.92(2) | *Ti* II 5.90(2) |
| 5188 | | | | 8.53(2) | 8.47(2) | | 8.71(2) | 8.85(2) | *Ti* II 8.70(6) |

TABLE II—*Continued*

| Approx. Wave-Length | γ Ori (B2) | β Tau (B8) | β Ori (B8p) | α CMa (Ao) | α Lyr (Ao) | α And (Aop) | ε UMa (Aop) | α Cyg (A2p) | Identifications |
|---|---|---|---|---|---|---|---|---|---|
| 5191 | | | | 1.60(2) | | 1.50(3) | 1.46(2) | 1.54(2) | *Fe* I 1.45(20); *Zr* II 1.60(7) |
| 5192 | | | | 2.71(2) | 2.35(2) | | 2.78(3) | | *Fe* I 2.34(30) |
| 5195 | | | | 5.05(2) | | 5.55(2) | 5.66(3) | | *Fe* I 5.47(8); *Fe* I 4.94(10) |
| 5197 | | | 7.42(2) | 7.67(3) | 7.52(3) | | 7.80(2) | 7.64(8) | *Fe* II 7.56(4) |
| 5201 | | | | 1.05(2) | | | | 1.23(2) | *S* II 1.00(2); *S* II 1.35(2) |
| 5205 | | | | 5.59(2) | 5.54(2) | | | 6.02(2) | *Y* II 5.73(80); *Cr* I 6.04 (200) |
| 5208 | | | | 8.67(2) | | | 8.69(2) | 8.31(2) | *Fe* I 8.59(7); *Cr* I 8.43 (300) |
| 5215 | | | | 6.16(2) | 6.14(1) | | 5.86(4d) | 5.63(3d) | *Fe* I 6.27(10); *Fe* I 5.18(6) |
| 5226 | | | 6.80(2) | | 6.58(2) | 6.05(2) | | | *Fe* I 6.87(15); *Ti* II 6.56(5) |
| 5227 | | | | 7.21(4) | | | 7.11(7) | 7.05(5) | *Fe* I 7.19(40) |
| 5232 | | | | 3.02(3) | | | 2.79(5) | 2.64(2) | *Fe* I 2.94(40) |
| 5234 | | | 4.36(2) | 4.90(3) | 4.64(2) | | 4.66(2) | 4.65(6) | *Fe* II 4.62(4) |
| 5237 | | | 7.16(2) | 7.44(3) | 7.35(2) | | 7.36(3) | 7.37(5) | *Cr* II 7.33(2) |
| 5243 | | | | 3.41(2) | | | 3.47(3) | | |
| 5247 | | | | 6.98(2) | | | 7.06(2) | | |
| 5251 | | | 1.13(2) | 1.16(2) | | | | 1.13(2) | |
| 5253 | | | | | | 3.13(2) | | 3.10(2) | |
| 5254 | | | | 5.08(2) | | | 4.69(3) | 4.86(3) | |
| 5257 | | | | 7.55(2) | | | 7.44(2) | 7.43(2) | *Fe* II 6.94 (*) |
| 5260 | | | 0.04(2) | 0.35(2) | 0.49(2) | 0.22(2) | 0.20(2) | 0.22(3) | |
| 5264 | | | | 4.86(3) | | | 4.33(3) | 4.61(3) | *Fe* II 4.81(1) |
| 5267 | | | 7.25(2) | 7.03(2) | | | | 7.01(2) | *Fe* I 6.56(30) |
| 5269 | | 9.69(2) | | 9.86(3) | 9.62(2) | 0.05(2) | 9.94(2) | 9.60(2) | *Fe* I 9.54(60); *Fe* I 0.36(30) |
| 5272 | | | 2.55(2) | 2.76(2) | | 2.33(2) | 2.41(2) | 2.37(2) | *Fe* I 3.16(5); *Fe* I 3.37(4) |
| 5275 | | | 6.14(2) | 5.65(4) | 6.08(3) | 5.75(3) | 5.67(6) | 5.81(8) | *Fe* II 6.01(6) |
| 5278 | | | 8.82(2) | | 8.98(2) | | | 8.55(2) | *Al* II 8.62(3) |
| 5279 | | | | 9.59(2) | | | 0.17(4) | 9.87(3) | *Cr* II 9.88 (pred); *Cr* II 0.11 (pred) |
| 5282 | | | | 2.09(2) | | | | | *Fe* I 1.79(10) |
| 5284 | | | | 4.05(3) | | 4.19(3) | 4.19(3) | 4.17(4) | *Fe* II 4.11 (pred); *Fe* I 3.62(18); *Al* II 3.77(8) |

TABLE II—*Continued*

| Approx. Wave-Length | γ Ori (B2) | β Tau (B8) | β Ori (B8p) | α CMa (Ao) | α Lyr (Ao) | α And (Aop) | ε UMa (Aop) | α Cyg (A2p) | Identifications |
|---|---|---|---|---|---|---|---|---|---|
| 5288 | | | | 8.53(2d) | 8.10(1) | | 8.02(1) | 7.86(2) | |
| 5289 | | | | 9.61(2) | 9.61(1) | | | | |
| 5291 | | | | 1.86(2) | | 1.21(2) | | 1.54(2) | |
| 5295 | | | | | | 5.45(4) | | | |
| 5297 | | | | | | | 7.87(4) | | |
| 5299 | | | | 9.27(2) | | 9.36(3) | | 9.01(2) | *O* I 9.00(5) |
| 5302 | | | | | 2.52(2) | 2.25(3) | 2.59(2) | 2.82(2) | *Fe* I 2.30(10) |
| 5305 | | | | 6.05(3) | 5.89(2) | 5.74(2) | 6.01(3) | 5.91(2) | *Cr* II 5.87(1) |
| 5308 | | | | | | | 8.37(2) | 8.28(2) | *Cr* II 8.43(1) |
| 5309 | | | | 9.05(2) | | 8.99(2) | | | |
| 5310 | | | | | | | 0.76(3) | 0.76(2) | *Cr* II 0.69(1); *Al* II 0.76(2) |
| 5311 | | | | 1.97(3) | | | | | *Zr* II 1.78(2) |
| 5313 | | | | 3.75(2) | 3.71(2) | | 3.65(3) | 3.55(3) | *Cr* II 3.59(1) |
| 5315 | | 5.17(2d) | | | | | | | |
| 5316 | | | 6.57(3) | 6.77(5) | 6.62(5) | 6.28(4) | 6.54(6) | 6.67(8) | *Fe* II 6.62(8); *Fe* II 6.78 (pred) |
| 5319 | | | | 9.38(2) | | | | 9.52(2) | |
| 5320 | | | 0.48(2) | | | | | | *S* II 0.70(7) |
| 5324 | | | | 4.72(2) | | | | | *Fe* I 4.18(30) |
| 5325 | | | 5.60(2) | | | 5.12(2) | 5.00(3) | 5.58(3) | *Fe* II 5.56(4) |
| 5328 | | | | 8.12(2) | | | 8.61(4) | 7.96(2) | *Fe* I 8.04(50); *Fe* I 8.53(15) |
| 5330 | | | 9.96(2) | | 9.96(2) | | 0.15(2) | 0.02(2) | *O* I 0.66(10); *O* I 9.59(7) |
| 5332 | | | | 2.52(1) | | | 2.54(2) | 2.36(2) | |
| 5334 | | | | 4.91(2) | | | 4.86(3) | 4.63(2) | *Cr* II 4.87(1) |
| 5337 | | | | 7.20(2) | | | 7.83(3) | 7.20(2) | *Cr* II 7.76(1); *Fe* II 7.73 (pred) |
| 5339 | | | 9.89(2) | 0.02(2) | | 9.35(2) | 0.60(2) | 9.89(2) | *Fe* I 9.93(12) |
| 5343 | | | | | 3.09(2) | | | 2.93(2) | |
| 5346 | | | | | | | 6.41(5) | | *Fe* II 6.54 (pred) |
| 5355 | | | | | 5.14(2) | 5.27(2) | | 5.14(2) | |
| 5363 | | | 2.89(2) | 3.12(3) | 3.48(2) | 3.10(3) | 3.12(3) | 2.89(5) | *Fe* II 2.87 (pred) |
| 5365 | | | 5.47(1) | 5.47(2) | | | | | |

TABLE II—*Continued*

| Approx. Wave-Length | γ Ori (B2) | β Tau (B8) | β Ori (B8p) | α CMa (A0) | α Lyr (A0) | α And (A0p) | ε UMa (A0p) | α Cyg (A2p) | Identifications |
|---|---|---|---|---|---|---|---|---|---|
| 5369 | | | | | | | 0.19(3) | 9.68(2) | *Fe* I 9.96(25n) |
| 5382 | | | | | | 2.73(2) | | 2.87(3) | |
| 5383 | | | | 3.41(2) | | | 3.41(2) | | *Fe* I 3.37(35n) |
| 5386 | | | 6.66(2) | 6.82(2) | | 6.81(3) | 7.25(2) | 6.85(2) | |
| 5390 | | | | | | 0.37(2) | 0.86(2) | 0.64(2) | |
| 5393 | | | | | | | 3.28(2) | 3.25(2) | *Fe* I 3.17(10) |
| 5396 | | | | | | 5.99(2) | 6.29(3) | 6.06(2) | |
| 5397 | | | | 7.02(2) | | | | | *Fe* I 7.13(40) |
| 5398 | | | | | | | 8.28(3) | 8.27(2) | |
| 5401 | | | | 1.94(2) | | | 1.93(3) | 1.85(2) | |
| 5404 | | | 4.73(2) | 4.47(2) | | | 4.47(1) | 4.51(2) | *Fe* I 4.14(30n); *O* I 4.87(3) |
| 5406 | | | | 6.06(2) | | | | | *Fe* I 5.78(40) |
| 5408 | | | | 8.26(2) | | | | 8.45(2) | *O* I 8.59(4); *Cr* II 7.62(1) |
| 5410 | | | | 0.95(1) | | | 0.87(3) | 0.89(2) | *Fe* I 0.91(15n); *O* I 0.76(3) |
| 5414 | | | 4.15(2) | | | 3.80(2) | | 4.15(2) | *Fe* II 4.08 (pred) |
| 5415 | | | | 5.13(2) | | | 4.89(4) | | *Fe* I 5.20(35n) |
| 5419 | | | | 9.14(2) | | | | | |
| 5421 | | | | 1.19(2) | | | | | |
| 5424 | | | | 4.52(2) | | | 4.55(3) | | *Fe* I 4.07(45n) |
| 5425 | | | | | | 5.27(2) | | 5.22(3) | *Fe* II 5.26 (pred) |
| 5427 | | | | 7.96(2) | | | 7.83(2) | | |
| 5428 | | | 8.74(4) | | 9.13(2) | | | | *S* II 8.64(5) |
| 5430 | | | | 0.04(2) | | | 9.99(2) | 0.01(2) | *Fe* I 9.70(40) |
| 5432 | | | 2.59(5) | 2.89(2) | | 3.11(3) | 3.08(2) | 2.92(3) | *S* II 2.77(9); *Fe* I 2.96(2n) |
| 5435 | | | | | | 5.47(2) | | 5.58(2) | *Fe* II 5.70 (pred); *O* I 5.78(6); *O* I 5.16(5) |
| 5436 | | | | 6.09(2) | 6.36(1) | | | | *Fe* I 6.60(2); *Ti* I 6.73(1); *O* I 6.83(8) |
| 5437 | | | 7.21(2) | | | | | | |
| 5438 | | | | | | | | 8.59(2) | |
| 5439 | | | | 9.61(2) | | | 9.72(2) | 9.80(1) | |
| 5445 | | | | 5.18(3) | | | | | *Fe* I 5.04(15n) |

TABLE II—*Continued*

| Approx. Wave-Length | γ Ori (B2) | β Tau (B8) | β Ori (B8p) | α CMa (Ao) | α Lyr (Ao) | α And (Aop) | ε UMa (Aop) | α Cyg (A2p) | Identifications |
|---|---|---|---|---|---|---|---|---|---|
| 5446 | | | | 6.59(3) | | | 6.60(2) | | *Fe* I 6.92(40) |
| 5448 | | | 8.86(2) | 8.73(2) | 8.94(2) | 9.14(2) | | | |
| 5454 | | | 3.94(5) | | | 4.08(2) | | 4.37(2) | *S* II 3.81(10); *Si* II 4.43(0) |
| 5455 | | | | | | | 5.83(4) | 5.59(2) | *Fe* I 5.61(40); *Fe* I 5.45(5); *Si* II 6.11(2) |
| 5462 | | | 2.30(2) | | | | | 2.22(2) | |
| 5462 | | | | 2.63(2) | | 2.71(2) | 3.08(2) | | *Fe* I 3.27(10n); *Fe* I 2.97(2n) |
| 5466 | | | | 6.60(2) | | 6.51(2) | 6.58(4) | 6.47(2) | *Fe* I 6.41(3); *Fe* I 6.99(1) |
| 5470 | | | | 0.53(2) | 0.07(2) | 9.99(2) | | | |
| 5472 | | | | | | | 2.87(3) | | *Cr* II 2.55(pred) |
| 5473 | | | 3.70(2) | | 3.95(1) | 4.17(2) | | 3.65(1) | *S* II 3.59(5); *Fe* I 3.91(3) |
| 5476 | | | | | | | 6.12(3) | | *Fe* I 6.56(10); *Ni* I .91(50) |
| 5477 | | | | 7.23(2) | | 7.52(2) | | | |
| 5478 | | | | | | | 8.42(3) | 8.31(2) | *Cr* II 8.38(1); *Fe* I 8.47(1) |
| 5481 | | | 1.34(2) | 1.20(2) | | | | | *Fe* I 1.25(2); *Fe* I 1.44(3) |
| 5482 | | | | 2.22(2) | 2.23(2) | 2.23(3) | 1.89(2) | 2.26(2) | |
| 5487 | | | | 7.55(2) | | 7.85(2) | 7.86(4) | 7.67(2) | *Fe* II 7.75(8) |
| 5491 | | | | | 1.45(2) | 1.42(2) | | | |
| 5502 | | | | 2.64(2) | 2.82(1) | | 2.87(4) | 2.46(2) | *Al* II 2.88(3); *Cr* II 2.09(1); *Cr* II 3.24(1) |
| 5506 | | | 6.31(2) | 5.99(2) | 5.97(1) | 6.32(2) | 6.26(3) | 6.18(2) | |
| 5509 | | | 9.77(2) | | | | | | *S* II 9.67(5) |
| 5510 | | | | 1.01(2) | | 0.56(3) | 0.69(3) | 0.99(2) | *Cr* II 0.74(1) |
| 5516 | | | 6.28(1) | 6.20(2) | | | | | |
| 5519 | | | | 9.00(2) | 9.16(1) | | | | |
| 5528 | | | | 8.75(2) | 8.43(2) | | | | *Mg* I 8.42(8r) |
| 5529 | | | 9.99(2) | | | | 9.50(3) | | |
| 5532 | | | | 2.18(2) | 2.52(2) | | | | |
| 5534 | | | | 4.95(3) | 5.00(2) | | 5.01(3) | 4.93(5) | *Fe* II 4.84(*) |
| 5544 | | | | 4.51(2) | | | 4.27(3) | 4.28(2) | [*V* II 4.62(10)] |
| 5554 | | | | | | | 4.50(3) | | |

TABLE II—*Continued*

| Approx. Wave-Length | γ Ori (B2) | β Tau (B8) | β Ori (B8p) | α CMa (A0) | α Lyr (A0) | α And (A0p) | ε UMa (A0p) | α Cyg (A2p) | Identifications |
|---|---|---|---|---|---|---|---|---|---|
| 5559 | | | | | | 9.03(2) | 9.23(2) | | |
| 5559 | | | 9.84(1) | 9.92(3) | | | | | |
| 5564 | | | 4.65(3) | | | | 4.76(3) | 4.38(2) | *S* II 4.94(4) |
| 5573 | | | 2.95(2) | 3.33(2) | | | 3.09(3) | | *Fe* I 2.84(30); *Fe* I 3.11(1) |
| 5578 | | | | | | 8.15(3) | 8.10(3) | 7.90(2) | |
| 5583 | | | | | | 3.59(2) | | 3.70(2) | |
| 5587 | | | 7.57(2) | 7.63(2) | | 7.41(2) | 7.16(3) | 7.77(2) | |
| 5588 | | | | | 8.43(2) | | 8.37(1) | | |
| 5605 | | | 5.94(4) | | 5.70(2) | | 5.72(1) | | *S* II 6.11(6) |
| 5615 | | | 5.92(2) | 5.77(3) | | | 5.52(2) | | *Fe* I 5.64(50) |
| 5620 | | | | | | | 0.58(3) | | *Cr* II 0.71(2); *Fe* I 0.50(1) |
| 5640 | 0.51(4) | 0.15(2) | 0.17(5) | | | | 0.38(2) | 0.40(2) | *C* II 0.50(2); *S* II 0.32(5); *S* II 9.96(8); *Si* II 9.49(2) |
| 5643 | | | 3.87(2) | | | | 3.87(1) | 3.73(1) | |
| 5645 | | | 5.64(2) | | | | 5.51(1) | | |
| 5646 | | | 6.73(4) | | | | | | *S* II 6.98(6) |
| 5647 | 7.84(3) | | | | | | | | *C* II 8.08(3) |
| 5655 | | | 5.66(2) | 5.47(2) | | | 5.27(2) | | *Fe* I 5.50(4) |
| 5658 | | | | | | | 8.13(3) | 8.02(2) | *Sc* II 7.89(25); *Sc* II 8.35(8) |
| 5659 | | | 9.85(3) | | | | | | *S* II 9.95(4) |
| 5664 | | | 4.52(2) | | | | | | *S* II 4.73(3) |
| 5667 | 7.26(3) | | | | | | | | |
| 5669 | | | 9.27(2) | | | | | | *Si* II 9.59(4); *Sc* II 9.05(12) |
| 5676 | 6.07(3d) | | | | | | | | *N* II 6.02(6) |
| 5679 | 9.85(4) | | 9.62(3) | | | | | | *N* II 9.56(10) |
| 5687 | 7.17(3) | | 7.17(2) | | | | | | |
| 5687 | | | | | 7.87(2) | | | 7.90(2) | |
| 5689 | | 8.89(2) | 8.85(2) | | | | | | *Si* II 8.86(2) |
| 5690 | | | | 0.72(2) | 0.52(2) | | | 0.66(2) | |
| 5696 | 6.76(5) | | 6.65(2) | | | | | | *Al* III 6.47(8) |

TABLE II—*Continued*

| Approx. Wave-Length | γ Ori (B2) | β Tau (B8) | β Ori (B8p) | α CMa (Ao) | α Lyr (Ao) | α And (Aop) | ε UMa (Aop) | α Cyg (A2p) | Identifications |
|---|---|---|---|---|---|---|---|---|---|
| 5700 | | | | | | 0.29(3) | | | |
| 5702 | 2.04(4) | | | | | | | | |
| 5706 | 6.09(3) | | | | | | | | |
| 5710 | | | 0.63(2) | | | | | | |
| 5722 | 2.72(3) | | | | | | | | |
| 5730 | | | 9.94(2) | | | 0.49(2) | | 0.16(1) | *Al* III 2.65(6) |
| 5737 | | | | | 8.08(1) | 7.86(2) | 7.83(2) | 7.89(2) | |
| 5740 | 0.54(3) | | | | | | | | |
| 5742 | | | | | 2.10(1) | | | 1.99(2) | *Si* III 9.76(8) |
| 5750 | 0.31(3) | | | | | | | | |
| 5780 | | | 0.07(2) | | 0.29(2) | | 0.23(3) | 0.05(2) | [*Fe* I 0.61(2)] |
| 5783 | | | | 3.57(2) | | | 3.37(2) | 3.42(2) | |
| 5790 | | | | | | | 0.64(3) | | |
| 5813 | | | | 3.44(2) | | | | 3.23(2) | |
| 5835 | | | | | | | 5.51(3) | | |
| 5850 | | 0.90(3) | | | | | | | |
| 5852 | | 2.78(3) | | | | | | | |
| 5859 | | 8.81(2) | | | 9.05(2) | | 9.03(2) | | *Ne* I 2.49(14) |
| 5862 | | | | 2.52(2) | | 2.29(2) | | | [*Fe* I 9.59(5)] |
| 5865 | | | 5.59(2) | | 5.49(2) | | | | *Fe* I 2.36(8) |
| 5871 | | | | 1.42(2) | 1.20(2) | 1.26(2) | | 1.63(2) | |
| 5875 | 5.77(15) | 5.59(7) | 5.73(10) | 5.62(3) | 5.86(4) | 5.90(6) | 5.69(2) | 5.78(5) | *He* I 5.62(10); *He* I 5.96(1) |
| 5889 | | | 9.75(5) | 0.12(6) | 9.86(8) | 0.01(3) | 9.99(6) | 9.88(15) | *Na* I 9.98(10R) |
| 5895 | | | 6.12(3) | 5.97(5) | 5.71(5) | 5.90(3) | 5.86(3) | 5.88(12) | *Na* I 5.94(8R) |
| 5905 | | 5.69(2) | 5.52(2) | | 5.68(2) | 5.74(2) | 5.58(1) | 5.74(2) | *Fe* I 5.67(3n) |
| 5913 | | | | 3.88(2) | | | 3.91(3) | | *Cr* II 3.91(1); *Fe* I 4.12(8) |
| 5915 | | | 5.26(2) | | 5.42(2) | 5.25(3) | | 5.35(2) | *Si* II 5.27(1) |
| 5916 | | | | 6.30(2) | | 6.19(2) | | | *Fe* I 6.26(3) |
| 5948 | | | 8.85(3) | | | | 8.70(3) | | Atm? |
| 5952 | | | 1.99(2) | | 2.11(2) | | | | Atm? |

TABLE II—*Continued*

| Approx. Wave-Length | γ Ori (B2) | β Tau (B8) | β Ori (B8p) | α CMa (Ao) | α Lyr (Ao) | α And (Aop) | ε UMa (Aop) | α Cyg (A2p) | Identifications |
|---|---|---|---|---|---|---|---|---|---|
| 5952 | | | | | | | 2.54(2) | 2.65(2) | [*Fe* I 2.73(3) |
| 5953 | | 3.29(2) | | 3.05(2) | | | | | |
| 5957 | | 7.78(2) | 7.89(4) | 7.53(2) | | 7.79(5) | 7.79(2) | 7.76(3) | *Si* II 7.61(5) |
| 5963 | | | | | 3.50(2) | | | 3.40(2) | |
| 5964 | | | 4.82(2) | | 5.00(2) | | | | |
| 5965 | | | | | | | 5.77(3) | | |
| 5975 | | | 5.15(2) | | 5.38(2) | 5.08(3) | | 5.37(2) | *Fe* I 5.36(4) |
| 5976 | | | 6.88(3) | | | | | 7.05(2) | *Fe* I 6.78(5) |
| 5978 | | | 8.79(3) | 8.68(3) | | | | 8.83(3) | *Si* II 8.97(7) |
| 5980 | | | | | | | 0.88(1) | 0.62(2) | |
| 5983 | | | | | | | 3.98(1) | 3.87(2) | *Fe* I 3.69(6) |
| 5985 | | | | | 6.17(2) | 5.81(2) | | 5.87(2) | *Fe* I 4.82(8); *Fe* I 7.07(6) |
| 6023 | | 3.77(2) | 3.69(2) | | | 3.94(2) | 3.96(2) | | *Fe* I 4.06(15) |
| 6083 | | | | | | 3.68(2) | | 3.81(2) | |
| 6089 | | | | | | | 9.54(3) | | *Cr* II 9.80(2) |
| 6097 | 6.99(2) | 7.36(2) | | | | | | | *C* II 8.62(3); *C* II 5.37(2) |
| 6122 | | | | | | 2.73(3) | | | |
| 6129 | | | | | | | 9.84(3) | | *Cr* II 9.23(1) |
| 6131 | | | | | | 1.38(3) | | | |
| 6141 | | | | 1.78(2) | | | 1.63(3) | | *Fe* I 1.73(4); *Ba* II 1.73(600r) |
| 6143 | | | 3.15(3) | | | 3.15(2) | | | *Ne* I 3.06(34) |
| 6147 | | | | | | | | 7.55(3) | *Fe* II 7.85(6) |
| 6148 | | | | 8.69(3d) | | | | | [*Fe* II 7.85(6); *Fe* II 9.25(4)] |
| 6149 | | | | | | | | 9.49(3) | *Fe* II 9.25(4) |
| 6156 | | | | | 6.19(2) | | | 6.13(2) | *O* I 6.78(8); *O* I 5.99(7) |
| 6157 | | | 7.36(3d) | 7.96(2d) | | | | | *Fe* I 7.73(4) |
| 6158 | | | | | 8.27(2) | | | 8.13(2) | *O* I 8.20(10) |
| 6158 | | | | | | | 8.82(3) | | *Cr* II 8.84(4) |
| 6179 | | | | | | | 9.21(3) | | *Cr* II 9.21(2) |
| 6238 | | | | 8.67(2) | | | 8.33(5) | 8.53(5) | *Fe* II 8.39(4) |

TABLE II—*Continued*

| Approx. Wave-Length | γ Ori (B2) | β Tau (B8) | β Ori (B8p) | α CMa (Ao) | α Lyr (Ao) | α And (Aop) | ε UMa (Aop) | α Cyg (A2p) | Identifications |
|---|---|---|---|---|---|---|---|---|---|
| 6247 | | | 7.50(3d) | 7.22(2) | 7.42(2) | | 7.31(5) | 7.55(5) | *Fe* II 7.56(4) |
| 6271 | | | | 1.42(2) | 1.22(1) | | 1.64(2) | | |
| 6272 | | | 2.42(2) | | | 2.54(2) | | | |
| 6273 | | | | | 3.09(2) | 3.15(2) | | | |
| 6285 | | | | | 5.88(2) | 5.57(2) | | 5.78(2) | |
| 6313 | | | 3.00(2) | | 3.17(2) | | | 2.86(2) | *S* II 2.68(6) |
| 6314 | | 4.58(2) | | | 4.81(2) | | | 4.79(1) | *Ni* I 4.67(15) |
| 6317 | | | | | 7.70(2) | 7.40(2) | | 7.62(2) | |
| 6323 | | | 3.53(2) | | | | | 3.64(2) | |
| 6324 | | 4.62(2) | | | 4.64(1) | | | | |
| 6327 | | | 7.19(2) | | | | | 7.35(2) | |
| 6332 | | 2.74(2) | | | 2.49(2) | | | | |
| 6334 | | | 4.73(2) | | | 4.48(4) | | 4.50(2) | *Ne* I 4.43(34) |
| 6342 | | | 2.37(2d) | | | | | | |
| 6347 | | 6.93(5) | 7.18(12) | 7.01(7) | 7.17(7) | 7.24(6) | | 7.09(12) | *Si* II 7.09(10) |
| 6350 | | | | 0.19(2) | | | | 0.30(2) | |
| 6351 | | | | 1.26(2) | 1.11(2) | | | | |
| 6356 | | | | | | 6.43(3) | | | |
| 6371 | | 1.42(3) | 1.49(10) | 1.47(5) | 1.50(5) | 1.53(5) | | 1.46(10) | *Si* II 1.36(8) |
| 6383 | 3.48(3) | 3.33(2) | | | | | | | *Ne* I 2.99(32) |
| 6385 | | | | | | 5.02(3) | | | |
| 6402 | 2.26(3) | 2.40(2) | 2.41(3) | | | | | 2.40(2) | *Ne* I 2.25(100) |
| 6416 | | | 6.98(2) | 7.02(2) | | 6.87(2) | | 6.93(3) | *Fe* II 6.92(2) |
| 6419 | | | | | | 9.43(3) | | | |
| 6432 | | | | | | | | 2.83(2) | *Fe* II 2.69 (pred) |
| 6454 | | | | | 4.35(2) | | | | *O* I 4.55(7); *O* I 3.69(6) |
| 6456 | | | 6.71(3) | 6.57(4) | 6.64(2) | 6.03(2d) | 6.58(4) | 6.60(6) | *Fe* II 6.40(6); *O* I 6.07(9) |
| 6459 | | | | | 9.77(2) | 9.71(2) | | 9.81(2) | |
| 6461 | | | 1.79(2) | | 1.90(2) | | | | |
| 6464 | | | 4.05(2) | | 4.26(2) | | | 4.41(2) | |

TABLE II—*Continued*

| Approx. Wave-Length | γ Ori (B2) | β Tau (B8) | β Ori (B8p) | α CMa (A0) | α Lyr (A0) | α And (A0p) | ε UMa (A0p) | α Cyg (A2p) | Identifications |
|---|---|---|---|---|---|---|---|---|---|
| 6466 | | | 6.54(2) | | 6.49(2) | | | | |
| 6467 | | | 7.77(2) | | 7.72(2) | 7.33(2) | | | |
| 6469 | | | | | | 9.66(3) | | | |
| 6470 | | | | | 0.33(2) | 0.31(3) | | 0.21(3) | |
| 6473 | | | 2.97(3) | | 3.02(3) | | | 2.97(3) | |
| 6488 | | | 8.94(2) | | 8.93(2) | | | | |
| 6497 | | | 7.66(3) | | 7.78(2) | | | | |
| 6503 | | | | | 3.80(2) | 3.77(2) | | | |
| 6507 | 7.29(3) | 7.15(2) | | | | | | | *Ne* I 6.53(40) |
| 6508 | | | 8.35(2) | | | 8.60(2) | | | |
| 6509 | | | | | 9.23(2) | | | 9.20(2) | |
| 6512 | | | 2.16(2) | | 2.38(2) | 2.35(2) | | 2.19(2) | |
| 6527 | | | | | 6.93(2) | | | 7.13(2) | |
| 6528 | | | | | 8.65(1) | | | 8.78(2) | |
| 6530 | | | | | 0.43(2) | | | 0.35(2) | |
| 6558 | | | 8.64(2) | | 8.55(3) | | | | |
| 6562 | 2.96(20) | 3.02(20) | (X) | 2.83(20) | 3.21(30) | 3.24(30) | 3.04(30) | (X) | *Hα* 2.82 |
| 6567 | | | 6.85(3) | | 7.26(3) | | | | |
| 6569 | | | | | 9.65(3) | | | 9.48(2) | *Fe* I 9.23(5) |
| 6571 | | | 1.52(4) | | | | | | |
| 6573 | | | | 2.96(2) | 3.17(2) | | | | |
| 6575 | | | | | 5.90(3) | 5.95(2) | | 5.59(3) | |
| 6578 | 8.03(4) | | 7.99(5) | | | | | | *C* II 8.03(10) |
| 6582 | 2.93(4) | | 2.81(4) | | | | | | *C* II 2.85(8) |
| 6583 | | 3.95(3) | | | 3.94(2) | 3.54(2) | | | |
| 6587 | | | | | 7.63(3) | 7.55(2) | 7.27(3) | 7.25(4) | |
| 6599 | | 9.44(3) | | | | | | | |
| 6669 | | | 9.34(3) | | | | | | |
| 6672 | | | 2.16(3) | | | | | | *Si* II 1.88(3) |
| 6675 | | | 5.00(3) | | | | | | |
| 6678 | | 7.90(8) | 8.00(10) | | | | | | *He* I 8.15(6); *Ne* I 8.28(32) |

# THE ASTROPHYSICAL OBSERVATORY OF THE CALIFORNIA INSTITUTE OF TECHNOLOGY

By GEORGE E. HALE

ABSTRACT

*Introduction.*—Gift by Rockefeller Trustees to California Institute of Technology of fund to establish an Astrophysical Observatory with 200-inch telescope; co-operation with Carnegie Institution of Washington.

*The 200-inch telescope.*—Selection of equatorial reflector; mirror disks; experiments with fused silica; adoption of new type of Pyrex glass, of low-temperature expansion; successful production of 60-inch, 120-inch, and 200-inch Pyrex disks; development of aluminum mirror surfaces; types of equatorial mountings; yoke type selected.

*Site.*—Choice between Northern and Southern hemispheres; mountain site near California Institute and Mount Wilson Observatory necessary for most effective work; five years' study of meteorological, topographical, and astronomical conditions at several favorable sites; other requirements; final selection to be made soon.

*Astrophysical laboratory.*—Purposes of laboratory; site in Pasadena on California Institute campus; brief description.

*Instrument shop.*—Purpose; site; equipment.

*Optical shop.*—Requirements; site; equipment.

*Auxiliary instruments.*—Attachments of 200-inch telescope; Ross correcting lens; tests with Mount Wilson telescopes; Rayton spectrograph lens; spectra of remote spiral nebulae photographed with 100-inch telescope; extremely short-focus lens designed by British Scientific Instrument Research Association; development of photographic amplifier by Stebbins and Whitford; use with 100-inch telescope; radiometers, etc.

A single decade includes two highly significant events in the endowment of research in America. On October 1, 1892, the University of Chicago, founded by John D. Rockefeller, opened its doors to students. About ten years later, on January 29, 1902, the trustees of the Carnegie Institution of Washington, established by Andrew Carnegie, held their first meeting in Washington. The first of these events marked the inception of the long series of national and international gifts for research which we owe to the generosity of the Rockefellers. The initiation of the Carnegie Institution also meant, not merely one of several large endowments by Carnegie, but the inauguration of an extensive plan for the development of research, subsequently strengthened by his establishment of the Carnegie Corporation of New York.

The Carnegie Institution of Washington, through its organization of widely distributed laboratories and observatories and the substantial aid given to its research associates in many educational

institutions, opened extraordinary opportunities for scientific investigation. The Rockefeller Foundation, the General Education Board, the International Education Board, and the Rockefeller Institute for Medical Research, with their broad and liberal policy, both national and international, proved admirably adapted to meet a wide variety of needs. The present undertaking, involving the co-operation of the Rockefeller and Carnegie groups, is but one of the countless results of their great gifts for the increase of knowledge.

The establishment of the Carnegie Institution's research departments at the most suitable sites, wherever found, could hardly fail to influence favorably the work of neighboring educational institutions. As a single example, the Mount Wilson Observatory may serve to illustrate this effect. In the northern part of California the Lick Observatory and the various departments of the University of California and Stanford University had long before reached a high plane, but in southern California little provision for research had been made prior to 1904. Pasadena, where some of the offices, laboratories, and instrument shops of the Mount Wilson Observatory were erected in that year, soon recognized the possibilities emphasized by the Carnegie Institution of Washington. In the course of time the policy of the California Institute of Technology, then known as Throop Institute, was completely remodeled. After the arrival of Dr. Arthur A. Noyes and Dr. Robert A. Millikan, an extensive plan of research in physics, chemistry, and other branches of science was developed at the Institute, and intimate co-operation with the Mount Wilson Observatory was begun. This rebirth of the Institute was made possible by gifts from many sources, both local and national. The interest of the Carnegie and Rockefeller boards having been thus aroused, their policy of encouraging such efforts came into play. Through their gifts, combined with those of many additional donors, the California Institute attained its present form. The foundation of the neighboring Huntington Library and Art Gallery, and its adoption of a research policy, added a third co-operating institution to the two already named. Pasadena thus became an active center of research and a favorable place, both climatically and intellectually, for the further development of similar undertakings.

Such considerations doubtless determined the Rockefeller boards, which had previously made large grants to the California Institute, to offer it funds in 1928 for the construction of a 200-inch reflecting telescope, together with all the buildings and equipment necessary to render this instrument as efficient as possible. Two conditions were made by the donors: the assurance of the active co-operation with the California Institute in this project of the Mount Wilson Observatory of the Carnegie Institution of Washington and the provision by the California Institute of an adequate endowment for the new Astrophysical Observatory. The president and Executive Committee of the Carnegie Institution, as well as the director of the Mount Wilson Observatory, quickly and cordially assented to the first of these conditions, while the trustees of the California Institute were no less prompt in agreeing to obtain an endowment.

Prior to the suggestion of President Wickliffe Rose of the International Education Board, the California Institute had not planned to establish a department of astronomy or astrophysics. The recent rapid development of astrophysics, however, and the great part in this development played by physics and chemistry, clearly made the most intimate possible co-operation between observatories and laboratories essential. A good beginning had already been made, but there was room for a still more effective union of effort. It was therefore decided to erect the Astrophysical Laboratory of the new Observatory next to the Norman Bridge Laboratory of Physics, in close proximity to the Gates Laboratory of Chemistry and not far from the Pasadena headquarters of the Mount Wilson Observatory.

The offer of the International Education Board was made at its annual meeting in May, 1928. After a visit of Dr. Rose and Mr. Thorkelson to Pasadena and Mount Wilson, the trustees of the California Institute voted early in July to proceed at once with the undertaking. They accordingly appointed an Observatory Council, consisting of four members of the Executive Council of the Institute: Robert A. Millikan, director of the Norman Bridge Laboratory of Physics and chairman of the Executive Council; Arthur A. Noyes, director of the Gates Laboratory of Chemistry; Henry M. Robinson, chairman of the Security First National Bank of Los Angeles; and the writer, honorary director of the Mount Wilson Observatory and

chairman of the Observatory Council, to take charge of the planning, construction, and operation of the Observatory. With the approval of President Merriam and Dr. Adams, several additional members of the Mount Wilson Observatory were authorized to join in the work. Accordingly, Dr. J. A. Anderson, of the Mount Wilson staff, was appointed executive officer of the Observatory Council. An Advisory Committee was established comprising Dr. Walter S. Adams (chairman), Charles G. Abbot, Ira S. Bowen, Paul S. Epstein, Edwin Hubble, Albert A. Michelson, Henry N. Russell, Frederick H. Seares, and Richard C. Tolman. To this Committee Professors T. von Karman, R. R. Martel, R. W. Sorenson, J. P. Buwalda, and W. H. Clapp have recently been added. Sir Herbert Jackson, director of the British Scientific Instrument Makers' Research Association, was appointed as research associate, and Francis G. Pease, of the Mount Wilson staff, and Russell W. Porter were named as associates in optics and instrument design. Sinclair Smith, of the Mount Wilson staff, and John Strong, formerly National Research Fellow in Physics have also joined in the researches involved in the project.

Dr. Walter S. Adams, who had attended all meetings of the Observatory Council from the beginning, was formally appointed a member of the Council in 1934, with the approval of the president and Executive Committee of the Carnegie Institution of Washington and the trustees of the California Institute. The president of the Carnegie Institution of Washington also appointed a co-operating committee, comprising Messrs. Adams (chairman), Hale, Hubble, and Seares, of the Mount Wilson staff, and Wright, of the Geophysical Laboratory of the Carnegie Institution of Washington, for the purpose of making a study of means through which the Carnegie Institution could contribute directly to aid in the furtherance of the 200-inch program. In the same year Captain Clyde S. McDowell, U.S.N., with long experience as a naval constructor, who had been given leave of absence from the Navy Department for this purpose, was selected as supervising engineer for the 200-inch telescope.

In harmony with the plan previously drawn up by the writer at the request of Dr. Rose, it was decided that the new Astrophysical Observatory thus provided for should include (1) a 200-inch re-

flecting telescope and other instruments, mounted at the most favorable high-altitude site to be found within effective working distance of Pasadena; (2) an Astrophysical Laboratory, on the campus of the California Institute, to serve as the Pasadena headquarters of the resident and visiting members of the research staff, the reduction of photographic and visual observations made with the 200-inch telescope and other instruments, the performance of experiments for the interpretation of these observations with the aid of apparatus supplementing that of the other laboratories of the California Institute and the Mount Wilson Observatory, the development of new instruments and methods of research, and the work of fellows and students in astrophysics: (3) Instrument and Optical shops, also on the campus of the Institute, for the construction of special apparatus and the figuring and testing of the mirrors and lenses required for the 200-inch telescope and other instruments.

The purpose of the present article is to describe in general terms the work thus far accomplished. It will be followed by other papers giving more detailed accounts of the various phases of the undertaking.

## THE 200-INCH TELESCOPE

In designing the instrumental equipment of the new Observatory the chief points to be borne in mind are (1) our purpose to supplement, rather than to duplicate, the existing apparatus of the Mount Wilson Observatory and the California Institute; (2) to multiply the efficiency of all our instruments not merely by increase in size but by every possible improvement in methods of design and construction and especially by the development of new auxiliary apparatus; and (3) to render the results of these investigations available at once to other observatories and research laboratories, where their immediate utilization might lead to new advances, long before the completion of the 200-inch telescope. As the annual reports of the Mount Wilson Observatory sufficiently indicate, this hope has been amply justified.

Our experience at Mount Wilson clearly demonstrates that the new telescope should be an equatorial reflector of large angular aperture, so mounted as to permit observation at the principal focus of the 200-inch mirror, at the Cassegrain focus below the large

mirror, and at the coudé focus within a constant temperature laboratory south of the polar axis. These possibilities exist in the case of the 100-inch Hooker telescope, but this instrument cannot reach the region surrounding the north pole (its farthest range in north declination is 63°58′), observation at its principal focus is difficult, and the time required to change the "cages" carrying the Newtonian and the two Cassegrain mirrors affects materially the observing program.

As for the optical parts, it was evident that in passing from a 100-inch to a 200-inch mirror a new type of disk would be required. The 100-inch mirror disk, made at St. Gobain of the best glass then available (ordinary plate glass), gives excellent results under almost all conditions. But even with the improved support system recently designed by Pease, it still shows at times sufficient change of figure with temperature to preclude the use of similar glass for a mirror of 200 inches aperture. The first step in the new undertaking therefore involved a comparative study of different means of making a suitable 200-inch disk.

*Mirror disks.*—After excluding one or two types of mirror disks which we and our advisers unanimously agreed to be unsuitable, the following possibilities remained: fused silica; some form of Pyrex glass; stainless steel or some other metallic alloy; and a special type of metallic disk, with a thin layer of glass of the same coefficient of expansion securely fused to its surface, proposed by the Philips Lamp Works of Eindhoven, Holland. Of these various materials, fused silica has the lowest coefficient of temperature expansion, and as Dr. Elihu Thomson and his associates had already made excellent small mirror disks of fused silica for use in telescopes, we arranged with the General Electric Company to have this investigation continued by Dr. Thomson and Mr. Ellis at the Thomson Research Laboratory at Lynn, Massachusetts. I trust they will publish a full account of the methods they devised and the results they accomplished. Only a brief statement regarding this long research is therefore included here.

In its earlier stages the process consisted in fusing a mass of nearly pure quartz sand in a circular electric furnace comprising the mold. The disk thus obtained, which contained a great number of bubbles,

was then ground to the approximate curvature desired and coated to a sufficient thickness with a layer of perfectly transparent fused quartz, free from bubbles. This layer was produced by spraying pure crystalline quartz, in finely granular form, on to the surface of the hot disk by means of an oxyhydrogen flame. Excellent mirror disks up to a diameter of 25 inches were produced in this way. Unfortunately, however, it finally became evident that the much larger disks required could not be made by this process.

With their well-known resourcefulness, Dr. Thomson and Mr. Ellis were not blocked by the difficulties thus encountered, which were due to the extremely high melting point of pure crystallized silica. They accordingly devised multiple spray burners of large size, suitable for laying down the entire disk within an electrically heated oven. The designing of suitable burners, the selection, granulation, and special treatment of quartz of the requisite purity, and the problem of supplying gas in sufficient quantities involved long and difficult researches. Finally they succeeded in producing a solid disk of fused silica with a diameter of about 66 inches and a thickness of 15 inches. The extraordinary qualities of fused silica are shown by the fact that this disk was cooled within nine days almost to room temperature without cracking. During the final stages of the process, however, the cover of the furnace was removed too soon through some misunderstanding of the workmen, and a radial crack developed, extending partially through the disk. In a second attempt an unbroken disk was obtained, but this was rendered unsuitable for optical purposes by pieces of fire brick falling from the cover of the furnace. Finally, in an effort to recoat one of these disks with pure silica, a failure at midnight in the electric-power supply resulted in another disaster.

Although it seemed probable that this process might ultimately lead to the production of suitable large blocks of fused silica, we reluctantly abandoned the attempt in the autumn of 1931 because of the very great cost, as then estimated, of the disks needed for our purpose.

Fortunately, our next line of attack was so strong that we could rely upon it with confidence. For many years the staff of the Geophysical Laboratory of the Carnegie Institution of Washington,

under the direction of Dr. Arthur L. Day, had been engaged in developing new types of glasses, of which Pyrex is the best known. Under the leadership of Dr. Day, these glasses have been manufactured by the Corning Glass Works at their factory in Corning, New York. Every housewife is familiar with the remarkable qualities of the Pyrex glass used for cooking utensils, as its very low coefficient of expansion permits it to be subjected to rapid change of temperature without cracking. Glasses of this general type thus offer qualities for telescope disks far surpassing those of the glass used for the 100-inch and all other large telescope mirrors.

During the last ten years we have become familiar with the good performance of ordinary Pyrex in the solar telescopes on Mount Wilson and my laboratory in Pasadena. In the case of the 200-inch mirror, however, it was necessary to know whether any danger of devitrification might arise during the period of annealing and also to solve various other problems involved in its manufacture. A long series of new investigations was accordingly undertaken at the Research Laboratory of the Corning Glass Works, under the personal supervision of Dr. Hostetter and Dr. McCauley. These studies led to the development of special methods of casting, preliminary cooling, and annealing, which proved very successful in the case of a 60-inch disk made at Corning in July, 1932. This disk, after careful consideration, had been designed by Dr. Pease and the Corning research staff with a ribbed back, which affords the necessary stiffness.[1] It also permits the use of a greatly improved support system, besides very materially diminishing the weight and the annealing time, as contrasted with a solid disk of the old type. Since the casting of this 60-inch disk a new Pyrex glass of still lower coefficient of expansion has been thoroughly tested at Corning, with highly satisfactory results. The many superior qualities of this glass include reduced annealing time and complete freedom from any danger of devitrification. An annealing oven for the 200-inch disk and the special apparatus for casting and handling disks of large dimensions were also built. The 120-inch disk, required for testing the 200-inch mirror during the process of figuring, was then cast and annealed

[1] A smaller ribbed coelostat mirror, made at Corning of Pyrex glass, has successfully passed very severe tests in our Optical Shop in Pasadena.

PLATE V

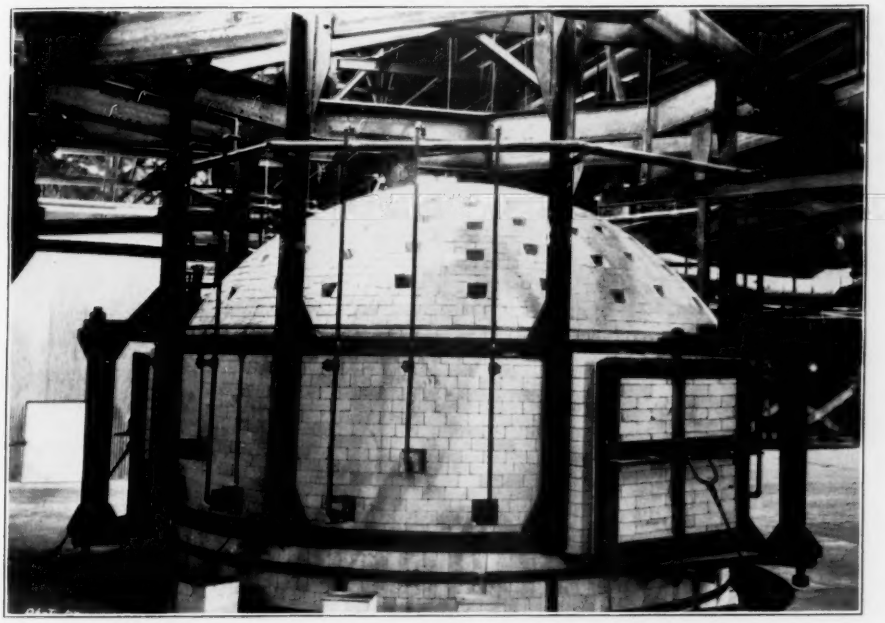

FIG. 1.—Beehive oven used to heat 120-inch disk and mold during the casting operation (Corning Glass Works).

FIG. 2.—Mold for 120-inch disk, showing cores for circular holes and triangular openings between ribs.

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FIG. 1.—Arrival of 120-inch disk at the Optical Shop, California Institute of Technology.

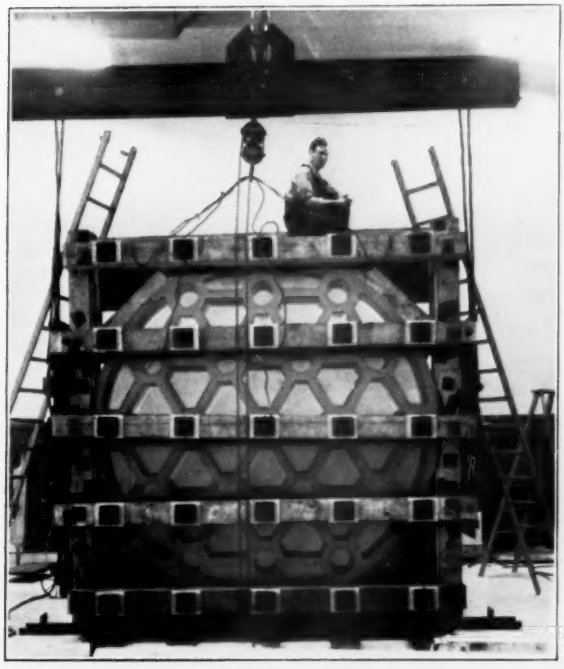

FIG. 2.—120-inch disk in crate

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PLATE VII

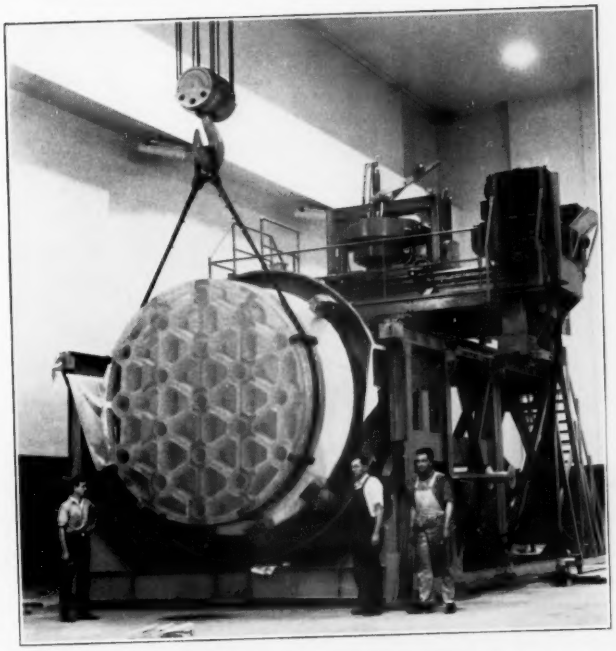

FIG. 1.—120-inch disk being placed on turntable of grinding machine.

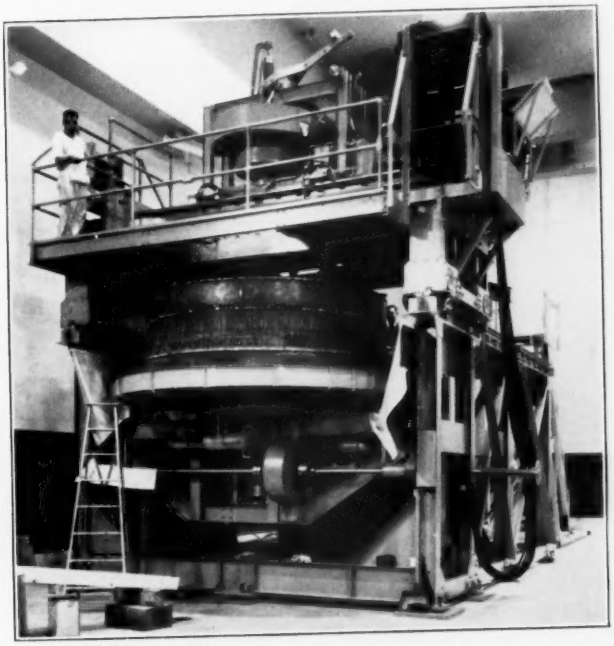

FIG. 2.—120-inch disk on grinding machine, with grinding tool in place.

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## PLATE VIII

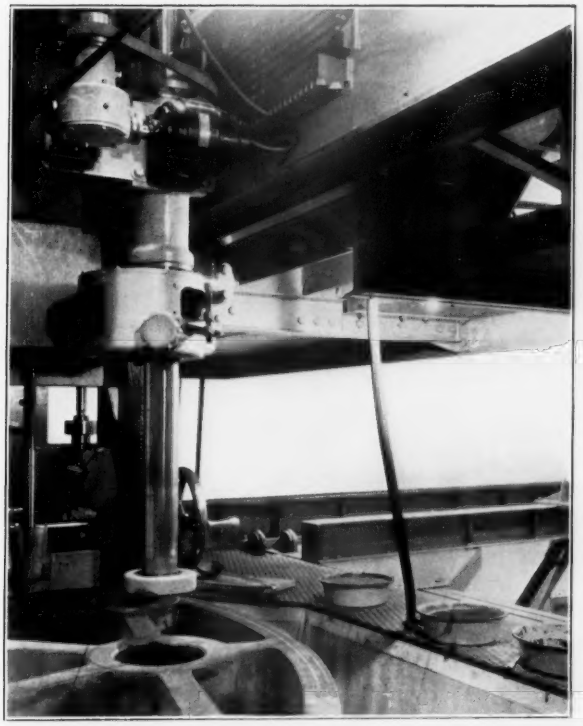

FIG. 1.—Apparatus for grinding pockets in back of 120-inch mirror for elements of support system (also used as edge-grinder).

FIG. 2.—The first 200-inch disk at the Corning Glass Works

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# PLATE IX

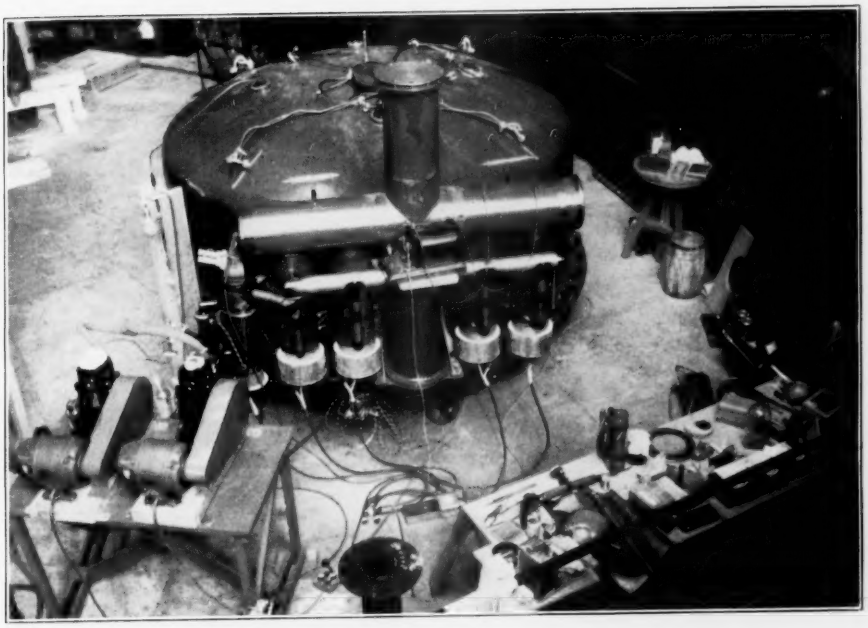

FIG. 1.—The aluminizing chamber and pumps

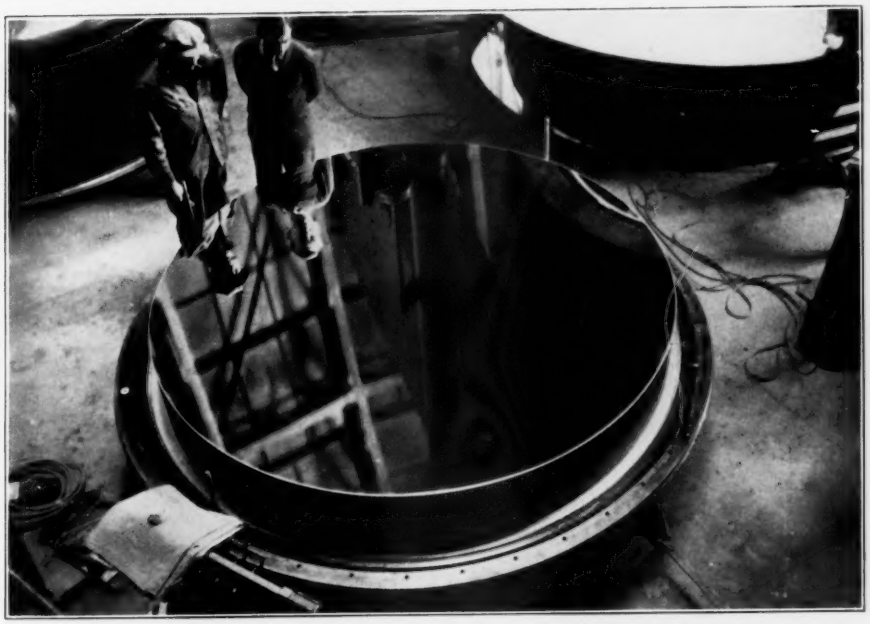

FIG. 2.—The 100-inch Hooker telescope mirror after aluminizing

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with great success (Pls. V–VIII). It is now being figured in our Optical Shop in Pasadena.

After the completion of the 200-inch mold and the casting of several large telescope disks for other observatories, a 200-inch disk was cast for us on March 25, 1934. The glass was poured from steel buckets containing 750 pounds each, and many hours were required to fill the mold, as only about one-half of the glass actually entered the mold from each bucket.[2] The extremely high temperature of the glass caused some of the supports of the mold material to break down near the end of the pouring process. Thus some portions of the mold rose into the molten disk. After a subsequent heating these were scooped out and the disk recooled. Although considerable work would be necessary to restore the symmetry of the rib system on the back of the mirror, this disk is being retained for possible use in case of any accident to its successor (Pl. VIII, Fig. 2).

The second 200-inch disk was poured with perfect success on December 2, 1934, into a greatly improved mold designed by Dr. McCauley, of the Corning Glass Works, who also designed the electric control system for gradually lowering the temperature of the disk during the annealing process, which will be completed before the end of the present year.

Reference has already been made to two other possible types of mirror disk. Through the co-operation of Dr. John Johnston, director of the Research Laboratory of the United States Steel Corporation, we have had an opportunity to examine several forms of stainless steel. These samples, and some others received from different sources, are of great optical interest, because of their heat conductivity, the permanent luster of their surfaces, and their high coefficient of reflection in the ultra-violet. Here they resemble speculum metal, and recall the fact that comparatively little stellar spectroscopic work has been done with large telescopes in the far ultra-violet since the early researches of Huggins. A 200-inch metallic disk probably could be made and subjected to special heat-treatment at relatively small expense, if it were needed.

An 8-inch glass-on-metal mirror, made for us by the Philips

[2] G. V. McCauley, "Making the Glass Disk for a 200 Inch Telescope," *Sci. Mo.*, **39**, 79, 1934.

Lamp Works, gave such remarkable results when subjected to sudden and violent heating while under optical test that we have obtained a 36-inch disk from this firm. This is intended for use with the vertical coelostat telescope of our new Astrophysical Laboratory. The thin glass surface, and the high heat conductivity of its ribbed metallic backing, fused to glass of the same coefficient of expansion, may afford important advantages for solar work.

*Aluminum mirror surfaces.*—In this connection reference should be made to the very successful experiments made by Dr. Strong, of the California Institute; Dr. Williams, of Cornell University; Dr. Edwards of the University of California at Los Angeles; and others in coating glass mirrors with metallic films of various kinds *in vacuo*. Some beautiful surfaces thus made by Dr. Strong in our Optical Shop are now in use at the California Institute, the Lick Observatory, and the Mount Wilson Observatory. Aluminum films are especially desirable from an optical point of view. Their coefficient of reflection is high over a long range of wave-length, they are very homogeneous and completely free from the thousands of minute scratches which produce so much diffuse light on all burnished mirrors, and they do not tarnish like silver. Dr. W. H. Wright, of the Lick Observatory, informs me that the 36-inch mirror of the Crossley reflector, after being coated here with aluminum by Dr. Strong, shows no measurable change in total reflecting power after the lapse of a year. Its surprising extension of stellar and nebular spectra in the ultra-violet has been illustrated by Dr. Wright in the *Publications of the Astronomical Society of the Pacific*. Very recently, with a large vacuum chamber and pumps built in our Instrument Shop at the California Institute, Dr. Strong has successfully coated the 60-inch and the 100-inch mirrors on Mount Wilson with aluminum (Pl. V). Their increased reflecting power and freedom from diffuse light are remarkable, as shown, for example, by photographs of such unequal double stars as Sirius. We therefore expect to use this process for the 200-inch mirror.

*The 200-inch telescope mounting.*—Telescope mountings vary widely in their requirements. Visual and spectroscopic observations do not suffer greatly from flexure in the mounting, but the demands of direct photography are much more stringent. We have studied

several possible designs for the mounting of the 200-inch telescope, and our investigation of the problem is still in progress. The engineers whom we have consulted call for two points of support, on opposite sides of the tube, and then endeavor to attain the greatest possible degree of rigidity conformable with the requirements of the optical design and the necessary range of motion in right ascension and declination.

As we wish to reach all parts of the sky visible in our latitude and to provide for the various optical combinations already mentioned, we have selected two possible mountings for rigorous comparison: the well-known fork type, first used on a large scale by Lassell for his 4-foot Malta reflector; and the English yoke type, illustrated in one form by the 100-inch Mount Wilson reflector. A yoke mounting, in another form suggested by Anderson, Edgar, and Serrurier, was recently embodied in a model built in our shop. The advantages of this modified yoke type, some of which were also included later in a modified fork type, are as follows:

The telescope tube, instead of being hung near its lower end between the arms of the yoke or fork, has its declination axis not far below its center. This increases its stability, and allows the use of a dome of much smaller relative diameter than the domes of the 60-inch or 100-inch reflectors on Mount Wilson.

The increased stability of the tube will allow the observer to be carried in a cartridge-shaped house at its principal focus, thus permitting the elimination of the large Newtonian mirror.

The troublesome and time-consuming task of changing the huge "cages" carrying the Cassegrain and Newtonian mirrors will be eliminated. There will be two Cassegrain mirrors, mounted in a tube extending a short distance below the principal focus of the 200-inch mirror. Each of these mirrors can be instantly turned into position by means of a worm gear, driven by an electric motor.

One of the convex mirrors will give at the secondary focus, just below the hole in the 200-inch mirror, a large and sharply defined star field, with a focal ratio of $f/16$ (equivalent focal length = 3200 in.). A stellar spectrograph with one, two, or three prisms will be mounted here, or a double-slide plate-carrier can be quickly substituted for the spectrograph when desired.

The same convex mirror, used in conjunction with a plane mirror standing at an angle of 45° with the axis of the telescope tube, will send the converging beam through the hollow declination axis to a totally reflecting prism, mounted before the slit of a long-focus grating or prism spectrograph. This spectrograph will be hung within a large hollow cylinder, supported parallel to the polar axis and so geared that the spectrograph slit will always remain vertical. A second cylinder on the opposite side of the polar axis will be provided to carry a radiometer or any other auxiliary instrument which must remain in a vertical plane. This ingenious scheme is a valuable feature of this form of mounting.

Another Cassegrain mirror, aided by the plane mirror suitably orientated, will send the converging beam toward the south pole through the hollow polar axis into a constant-temperature chamber, as in the case of the 100-inch telescope. This will permit the use of a fixed spectrograph or other auxiliary apparatus of any focal length desired.

On account of the importance of securing a completely satisfactory mounting and dome, a large amount of time and effort have been devoted to this study. A preliminary fork design made in Pasadena by Mr. E. P. Burrell, of the Warner and Swasey Company, in conjunction with our local group, was followed by the modified yoke design already mentioned, and then by a second fork design. Captain McDowell has just completed an extensive investigation of constructional facilities in various parts of the country, and a final comparative study of the problem, calling in the aid and experience of many able engineers and men of science, is now under way.[3]

It will probably be advisable to include within the lower part of the building supporting the dome a small instrument repair shop, several dark rooms, a laboratory for adjusting and testing instruments, and some other requirements.

## SITE

The question has sometimes been raised whether the 200-inch telescope would not be more useful in the southern hemisphere. As

[3] Since this paper was written, and after a complete analysis of the various types by the firm of Lessells & Karelitz, Professor Timoschenko, and many other leading engineers, the Advisory Committe and the Observatory Council have voted unanimously to adopt the yoke type of mounting.

all astronomers will recognize, a very large telescope, having a small field, should be rarely employed for scouting purposes and never for work within the ready range of smaller instruments. It must be devoted almost exclusively to the study of selected objects. Thus the vastly greater knowledge of stars and nebulae acquired during centuries of observation north of the equator is precisely what is needed in making adequate selections for more intensive study. Moreover, nearly two-thirds of the nearest extra-galactic nebulae, offering the greatest possibilities of research, can be observed only from a northern station. The importance of a detailed investigation of such unique spirals as the Great Nebula in Andromeda and Messier 33, with the highest instrumental power, cannot be overstated. As for the brightest stars, the only ones available for spectroscopic examination with very high dispersion, three-quarters of them are accessible from Mount Wilson. Then, too, our existing knowledge of tens of thousands of faint stars and millions of very remote nebulae, derived from many years of work with the largest existing telescopes, provides the necessary means of selecting suitable objects for further investigation with the 200-inch telescope. Finally, the southern hemisphere can at present furnish no co-operating research institutions comparable in staff and equipment with the California Institute and the Mount Wilson Observatory.

It is, however, very desirable that much work be done south of the equator with large telescopes, thus gradually preparing the way, as in the north, for another instrument as large as the 200-inch telescope.

A long study of meteorological, topographical, and astronomical conditions, reinforced by more than thirty years of experience at Mount Wilson, leaves no room for doubt regarding the advantages of the southwestern corner of the United States as the site for a 200-inch telescope. Its latitude gives access to the whole of the northern heavens, as well as a broad zone south of the celestial equator. Its mountain ranges afford easy means of escape from the dense air of the lower atmosphere, which not only produces poor images but absorbs and scatters much light. On some of the mountains of southern California the daily range in temperature is remarkably low, while the annual range is moderate. A large daily range is very

objectionable, because of the difficulty of preventing distortion of the telescope mirrors and its effect on the telescope mounting and auxiliary instruments. A large annual variation is also to be avoided, as this means low winter temperatures and greatly reduced efficiency of the observer. The average wind velocities, as shown by the Mount Wilson and other mountain records, are also very low, while the comparative freedom from clouds permits observations to be made on a large percentage of nights during the year. All these favorable conditions are readily explained when the paths of the principal storms in the United States are taken into account.

Dr. Wickliffe Rose repeatedly expressed the hope that a site easily accessible from Pasadena would be chosen, so as to permit the readiest co-operation between the staffs of the Mount Wilson Observatory and the California Institute. Our experience in the past and our recent astronomical and meteorological studies confirm this view. In fact, if it were not for the great increase of electric lights in the San Gabriel Valley since our first occupation of Mount Wilson, it is probable that a site adjoining the 100-inch Hooker telescope might prove most suitable. While it is true that even now these lights affect slightly but a few classes of work, and then only in the case of objects south of the zenith, they would be more troublesome with the 200-inch telescope on such occasions because of its larger aperture.

In a later article Dr. Anderson, who has been in immediate charge of our recent site investigation, will describe in detail the special instruments employed, the simultaneous tests of seeing made by several trained observers at many different points, the visual, photographic, and photo-electric cell measurements of sky brightness, and the conclusions derived from airplane flights.

In general, it may be said that the Tehachapi Mountains form an important barrier against the greater cloudiness and increased rainfall to the north. South of this range there is also decreased atmospheric disturbance because of greater distance from the centers of the most typical cyclonic storms moving eastward from the Pacific Ocean near the Canadian border. Local conditions, however, may affect particular sites. Thus the mountains at the eastern end of the San Gabriel Valley are very much more subject than Mount Wilson

to the thunderstorms that may interfere so seriously with summer observations still farther east. On the other hand, these mountains serve as a most advantageous wall between the desert and the sea, affording admirable protection to many promising mountain sites. After a five-year study of the best of these, all exceptionally free from local atmospheric disturbances and the effect of city lights, we have provisionally selected a nearly level tract of land on the summit of Palomar Mountain, which lies about 93 miles southeast of Pasadena and 50 miles north of San Diego.

In his valuable report to the Carnegie Institution of Washington on possible sites for an astrophysical observatory, the late Professor W. J. Hussey, then of the Lick Observatory, gave an excellent survey of the atmospheric conditions in southern California.[4] Equipped with a portable 9-inch Clark refractor, he examined several mountain sites lying within the region extending from the Mexican border to the ranges lying north and east of Los Angeles, and added many useful comments on the topographical and climatic conditions in this portion of the Southwest. After following up his telescopic tests over a much longer interval of time, I fully agreed with his tentative selection of Mount Wilson, where I began work in the winter of 1903–1904.

Among other sites inspected by Professor Hussey was Mount Palomar (latitude 33°21′20″, altitude about 6100 ft.). However, after long consideration, he thought Mount Wilson would be preferable to Palomar, partly because of its easy accessibility from Los Angeles and Pasadena. At that time, in the absence of motor cars and roads worthy of the name, Palomar was very difficult to reach. Moreover, Hussey had ascended the mountain from a station on Cuyamaca, about 30 miles toward the southeast, where the conditions were poor and the desert near. Impressed by his unfavorable tests at Cuyamaca, he feared similar atmospheric disturbances at Palomar, and did not take his telescope there, though he regarded it as the most promising site in San Diego County.

We have no reason to regret Hussey's choice, as Mount Wilson has proved to be an admirable site, and even since the great increase of population in the San Gabriel Valley and the consequent multiplica-

[4] *Year Book No. 2, Carnegie Institution of Washington*, December, 1903.

tion of electric lights, we would not wish to move the Observatory. The choice of a site for a telescope of the large linear and angular aperture of the 200-inch is, however, a different problem under present conditions. The darkest possible sky is required for long-exposure direct photography at the principal focus of the large mirror, in addition to such low wind velocity and other good qualities as Mount Wilson enjoys.

Through the courtesy of Dr. Marvin, lately chief of the United States Weather Bureau, several sets of recording instruments were loaned to us for a considerable period. One of these sets was kept in operation on Palomar for five years, so that we are now well informed regarding the meteorological conditions. Many tests of seeing, made by several skilled observers of the Mount Wilson staff, have also been made there. These show that the average seeing differs very little from that at Mount Wilson, though Ellerman frequently found the Palomar seeing superior. The average wind velocity and rainfall are also similar at the two sites. As for accessibility, we are promised by the San Diego County authorities a broad and well-surfaced road, of about half the grade of the Mount Wilson Toll Road, and the motor trip from Pasadena can now be quickly made over perfect concrete routes. If other necessary conditions are fulfilled, and if we can be certain of permanent protection from all appreciable sources of disturbance, the 200-inch telescope will presumably be erected on Palomar Mountain. But other excellent sites are available.

Before outlining the studies of auxiliary apparatus and methods hitherto made, brief descriptions of the buildings and instruments erected on the campus of the California Institute may be given.

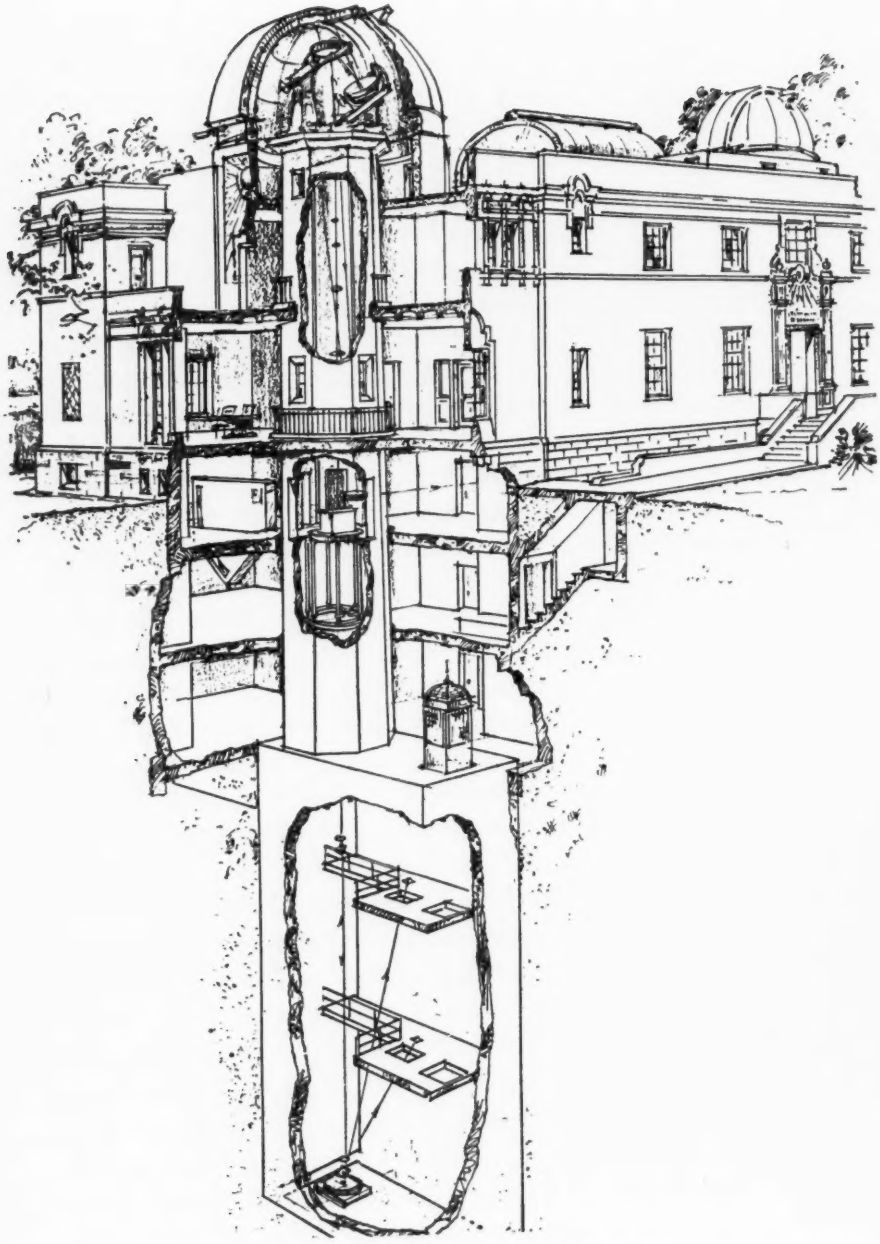
## THE ASTROPHYSICAL LABORATORY

Our experience at the Mount Wilson Observatory has demonstrated beyond question the many advantages of having the headquarters of its staff in Pasadena. The mild climate of the San Gabriel Valley, the possibility afforded the various families to share in the amenities of an attractive residence city, the facility of cooperation with the California Institute, the change of scene enjoyed by the observers in dividing their time between the mountain and

the town all contribute materially to greater efficiency. Furthermore, the members of the laboratory staff, computing division, and instrument shops, who rarely require access to the telescopes on the mountain, can work to much better advantage in Pasadena.

Similar conditions will apply in even greater degree to the new Astrophysical Observatory. Its Astrophysical Laboratory, standing in close proximity to the Norman Bridge Laboratory of Physics, the Gates Chemical Laboratory, and the many other related departments of the California Institute, could hardly be more favorably situated (Pl. X, Fig. 1). Designed and equipped so as to supplement these departments, as well as those of the Mount Wilson Observatory a few blocks away, it embodies many ideas generated in both institutions during the last thirty years.

In planning the building, which was designed by the Goodhue Associates in harmony with the general type of architecture adopted by the late Bertram Goodhue for the California Institute, we have profited in many respects by this experience. One of the excellent features of the Bridge Laboratory, for instance, is its extension under ground, where the constancy of temperature is so useful. As will be seen from the cross-section shown in Figure 1, the Astrophysical Laboratory has two and one-half stories under ground, in addition to the rectangular well (13 by 30 by 60 ft.) containing the 75-foot spectrograph and other instruments. Springing from the massive reinforced concrete walls of this well, at a point 28 feet below the ground level, is the octagonal steel and concrete tower, extending to a height of 68 feet and free from contact with the floors or walls of the building. This tower carries the coelostat telescope (Pl. X, Fig. 2), with plane mirrors 36 and 30 inches in diameter, the second of which sends the solar beam nearly vertically downward, where it falls upon a 26-inch concave mirror 47 feet below the second flat of the coelostat. This concave mirror returns the beam to one of three smaller convex mirrors of fused silica, so mounted that each can be turned into position above the vertical axis of the 75-foot spectrograph. The system is therefore that of the "skew Cassegrain," which I have used successfully in my Solar Laboratory in Pasadena. These convex mirrors give solar images 22, 14, and 7 inches in diam-



SECTION OF THE ASTROPHYSICAL LABORATORY

PLATE X

FIG. 1.—Astrophysical Laboratory at the California Institute

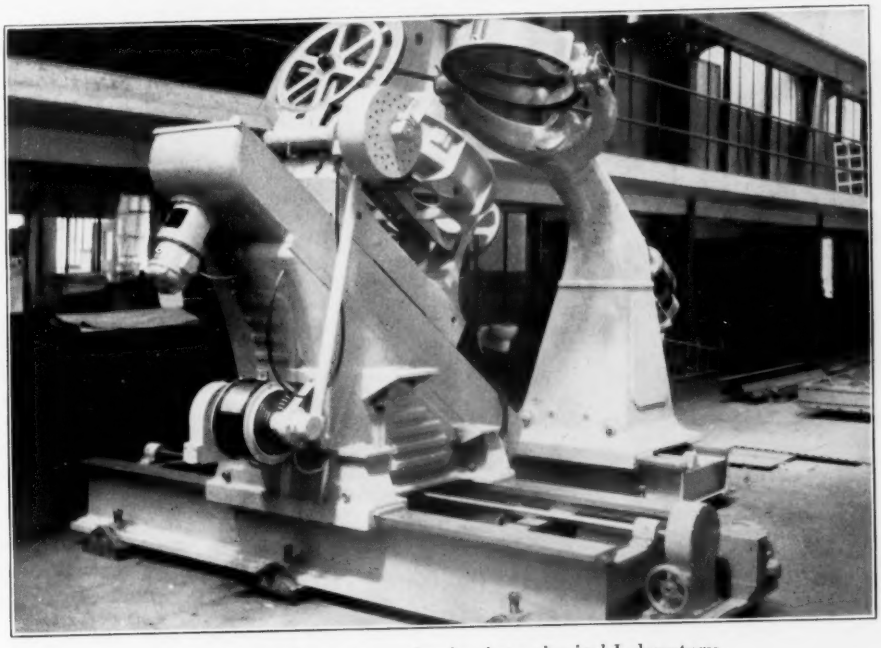


FIG. 2.—Coelostat mounting for Astrophysical Laboratory

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eter, respectively, on the slit of the spectrograph. With other optical combinations smaller images of the sun, for visual observation with a spectrohelioscope or photography with a spectroheliograph, both mounted in the well, can also be obtained. No detailed description of this spectrographic outfit need be given here, but it should perhaps be added that its design permits great flexibility of arrangement, including Littrow combinations 8 inches in aperture—of 38 feet and 75 feet focal length, respectively—as well as other arrangements such as a 75-foot collimator combined with a 10-foot camera, an 18-foot camera, a 30-foot camera, etc. In these combinations large plane gratings or liquid prisms may be used, in accordance with the requirements of the investigation in progress. The various levels of the spectrograph well are easily reached by means of a small elevator. Needless to say, the entire massive head of the spectrograph can be rotated in position angle, as well as the grating or prism support beneath it in the well. Of course, provision is also made for such attachments as the special polarizing apparatus required in the study of solar magnetic phenomena. The auxiliary apparatus also includes a large magnet for work on the Zeeman effect; an electric furnace; and arcs, sparks, and vacuum tubes, with the necessary controls and transformers. Mounted for use with the solar image, there will also be a special interferometer spectrograph, designed to supplement the present interferometer of the Mount Wilson Observatory. This brief account of the vertical coelostat telescope and its auxiliaries may suffice for the purpose of a preliminary article. As for the general design of the Astrophysical Laboratory, the width of the main building (east and west) is 57 feet, while its length is 128 feet (Fig. 1). There is also an extension at the northeast end, chiefly underground, 41 feet wide and 51 feet long. This contains the motor generators and other machinery, ventilating apparatus, etc.

In addition to the domes and special housings for its larger instruments, provision is made for the offices of the staff and research students, computing rooms, dark rooms, a seminar room, etc. These are distributed as follows:

On the roof are the 23-foot dome of the coelostat telescope, a rolling house covering a "solar furnace" (consisting of nineteen 24-in. lenses and the same number of condensing lenses, equatorially

mounted, which concentrate the solar rays at an immovable focus), a spectrograph for use with the solar furnace, a 17-foot dome for a short-focus Schmidt photographic telescope of 24-inch aperture, and a small transit instrument for the use of students.

The second floor contains thirteen offices for members of the staff and six north rooms for measuring instruments.

On the first floor are the library, a seminar room, and ten offices for members of the staff and research students.

The principal laboratory on the basement floor is cruciform, surrounding the head of the 75-foot spectrograph. Openings into the tower will admit light to the slit from arc, spark, furnace, and other sources, mounted in convenient positions. Here also will be a magnet for the Zeeman effect, and the large interference spectrograph, upon the slit of which a solar image of any desired diameter can be formed. A tunnel connects this laboratory with the electric power plant. There are five other laboratories on this floor, one of which will contain a vertical concave grating spectrograph of 21-foot focal length. In addition there are six photographic dark rooms, an instrument shop, a glass-blowing laboratory, a switchboard room, and a long optical testing tunnel.

The sub-basement contains a large laboratory surrounding the tower; several rooms for general research; photographic, photometric, and chemical laboratories; storage battery room; and six photographic dark rooms. At this level, in the annex, are the large machines of the power plant, while the transformers, etc., are also in the annex on the main floor.

The second sub-basement contains storage vaults for astronomical and physical photographs, cabinet files, rooms for stereocomparators, microphotometers, and other special measuring instruments, several general laboratories, supply closet, pump room, and apparatus storage room.

The building of the Astrophysical Laboratory has been completed, and the coelostat telescope, designed and constructed in our shops, has been mounted on the tower. Some of the other equipment is also in place, but the 75-foot spectrograph is not yet ready, and other apparatus is under construction.

PLATE XI

FIG. 1.—Instrument Shop

FIG. 2.—Optical Shop

INSTRUMENT SHOP

Ever since my first work in spectroscopy fifty years ago I have increasingly realized that a combination of observatory, laboratory, and instrument shop is essential in our chosen field of astrophysical research. Thus while for large and important pieces of routine work, requiring the continued use for many years of the same instruments and methods, an instrument shop may be unnecessary, it is indispensable if rapid advances are to be made in developing the special devices required in the initiation of new methods. The instrument shop of the Mount Wilson Observatory is as busy today as it was when constructed thirty years ago, and future advances will continue to depend upon its operation.

The first requirement of the new Astrophysical Observatory was therefore a suitable instrument shop, with modern machine tools adequate to deal with the problems in view. While these tools need not be large enough to permit the construction of such a huge instrument as the 200-inch telescope mounting, they must be chosen with reference to the scale of its auxiliary apparatus, and also with an eye to the requirements of our optical work. Here again our experience at the Mount Wilson Observatory was called upon as a guide, with results which thus far have proved very satisfactory.

The site of the Instrument Shop was easily determined in the light of the same experience. It should be in close touch with the Astrophysical Laboratory and also with our Optical Shop. At an early stage of this undertaking, when it appeared likely that the 200-inch mirror might have to be cast and figured at its permanent site, the question of shop location seemed less simple. But when it became evident that the best procedure would be to utilize the factories of the General Electric Company or the Corning Glass Works for the manufacture of the large disks, the solution adopted became obvious. A site on the campus of the California Institute also carries with it many other advantages, which need not be enumerated here.

The Instrument Shop, shown in Plate XI, Figure 1, is a one-story (and mezzanine) building of reinforced concrete 70 by 197 feet, facing on California Street and adjoining the Optical Shop. It is well lighted, both by windows on the north and south sides and by in-

clined skylights of the "sawtooth" type, familiar in machine-shop construction. Its broad doorway to the east, opening into the arched entranceway connecting it with the Optical Shop, easily permits the passage of a loaded motor truck or the admission of large grinding tools used for figuring the telescope mirrors. A 5-ton electric crane runs overhead through the central bay, greatly facilitating the handling of heavy castings. In the southwest corner is the pattern and woodworking shop, 20 by 88 feet, equipped with benches, pattern lathe, 36-inch band saw, 30-inch disk and spindle sander, vertical borer, speed lathe, circular saw, two-speed surfacer, and a planer and jointer, all motor-driven, with various attachments and the necessary hand tools.

The central bay, about 20 feet wide, contains some of the larger machine tools, while others occupy the wide area on the south front, east of the pattern shop. North of the central bay are rooms for painting and lacquering, hardening (with furnace), forging and welding, grinders, a shop for small instrument work, offices, tools and supplies, metal stock, and a gear-cutting shop. A partial mezzanine floor contains drafting-rooms, steel storage balcony, etc. The basement, most of which is unexcavated, contains a transformer vault, a switchboard room, locker and storage rooms, and space for the refrigerating machinery required for the Optical Shop.

The machine tools, which are all motor-driven, include one horizontal boring, drilling, and milling machine; one 36 by 36 inch open side planer; one 25 by 50 inch sliding bed gap lathe; one 16 by 60 inch lathe; one 12 by 24 inch universal and tool grinding machine; two 13 by 48 inch lathes (one with precision lead-screw); one 28 by 10 by 18 inch universal milling machine; one 36-inch gear hobber for cutting spur, worm, and helical gears; two single-spindle sensitive drill presses; one 20 inch by 16 foot lathe; one 4-foot radial drill; one 20-inch metal-cutting band saw; one 9-inch precision lathe; one small duplex milling machine; one 20-inch standard shaper; two high-speed metal-cutting machines; two arbor presses; one 9-inch bench lathe; two high-speed grinders; two 14 inch by 6 foot Economy lathes; and one 300-ampere portable welding set, welding and cutting blowpipes, etc.

The superintendent of the Instrument Shop, Mr. G. W. Sher-

burne, had many years of experience at the Mount Wilson Observatory, both in the construction of instruments and in the erection of the 100-inch telescope.

### OPTICAL SHOP

The task of designing an optical shop in which a 200-inch paraboloidal mirror can be made and accurately tested necessarily involves much experience and study. The building must be large enough to permit Foucault or other tests of extreme delicacy to be applied in connection with a 120-inch mirror; the air within it must be of great homogeneity and nearly constant in temperature and humidity; and the effects of vibration from any source must be eliminated. An overhead crane capable of carrying very heavy loads must be provided. Moreover, several smaller rooms for work on auxiliary mirrors and grinding and polishing tools are required. These conditions, combined with the fact that the building and all its machinery must remain available for many years to permit of additional optical work and the refiguring of the large mirrors in case of any possible slow changes in form or polish, indicate that no temporary structure will meet the rigorous requirements of the problem.

The Optical Shop shown in Plate XI, Figure 2, recently erected adjoining the Instrument Shop just described, is proving itself to be suitable for our needs. The architectural design, made by Mr. G. W. Iser, embodies the ideas of Messrs. Anderson, Pease, Porter, and other members of our staff, combined with principles of construction due to Professor R. R. Martel and a scheme of heating, cooling, and ventilating worked out by Messrs. Hunter and Hudson. The outside dimensions of the main building, which consists of a single room just large enough for figuring and testing the 200-inch mirror, are 57 by 178 by 50 feet. The interior height of this room, from insulated concrete floor to ceiling lined with 2-inch cork, is 39 feet. Above it is an attic about 8 feet high, fully ventilated by numerous ducts, to protect the ceiling from the heat of the sun on the roof. Adjoining the main building on the west is an annex of two stories and basement, containing the smaller rooms and testing tunnel needed for work on mirrors up to 36 inches in aperture.

The entire building is constructed of concrete, heavily reinforced

with steel, and the walls are lined with 3 inches of cork. At the south end of the main room is an observation gallery, completely glassed in, from which visitors can see the optical work in progress. A special air-conditioning system, designed to meet our specifications, regulates the temperature and humidity of the air. The overhead electric crane, provided with the fast and slow motions required in handling the large mirrors, runs the entire length of the room. This has been tested with a load of 62 tons, and proves to be well adapted for its purpose.

The grinding machine for the 120-inch mirror was designed and constructed in our shop, and the 200-inch grinding machine is now being built there. The following machines are used in the smaller rooms of the optical annex, where the lenses for the solar furnace were made and the coelostat mirrors are being figured: a 2-foot grinding and polishing machine; a 4-spindle grinding and polishing machine for small work; a 2-spindle horizontal grinder with 24-inch and 42-inch plates; a portable edge grinder for disks from 18 to 60 inches aperture; a small edge grinder for lenses and disks up to 14-inch aperture; a high-speed portable bench grinder for small lenses; a 17-inch drill press used as a "biscuit cutter,"; a 3-foot grinding and polishing machine (loaned by Mount Wilson Observatory); three knife-edge testing outfits; and miscellaneous machine and hand tools. A 60-inch grinding machine, when needed, can be borrowed from the Mount Wilson Observatory.

Dr. John Strong occupies a laboratory at the north end of the building, where he has developed his process for coating mirrors with aluminum.

Mr. M. H. Brown, with several assistants, is now grinding the 120-inch Pyrex disk, after completing a large number of smaller mirrors and lenses.

## AUXILIARY INSTRUMENTS

The auxiliary instruments for the Astrophysical Observatory and Laboratory are of three classes: (1) those used as attachments or auxiliaries of the 200-inch telescope, (2) those required for the observational and experimental work of the Astrophysical Laboratory, and (3) those needed for the measurement and reduction of astro-

nomical and physical photographs. Some of the chief instruments of the Laboratory, such as the tower telescope and spectrographs and the solar furnace, have been mentioned above. Six machines for measuring spectra have been built in our shop, and two microphotometers, which are constantly in use, have been purchased. Without dwelling on other apparatus falling under (2) and (3), the concluding section of this paper may be devoted to the attachments of the 200-inch telescope.

It goes without saying that if the efficiency of a large telescope can be doubled or trebled by devising some small and relatively inexpensive attachment, this method of procedure is decidedly preferable to a large and expensive increase in aperture. We have therefore carried on a series of investigations with this end in view.

*Ross correcting lens.*—The importance of multiplying the photographic range of the 200-inch reflector in order to permit the study of very faint or remote stars and nebulae led to the adoption of the ratio $f/3.3$ for the large mirror. Such a ratio implies a very small field, and one of our first moves was to find a means of obviating this difficulty without changing the ratio of focal length to aperture. Accordingly, Dr. Frank E. Ross, of the Yerkes Observatory, who has had long experience in designing lens systems, was invited to attack the problem of devising a correcting lens of zero power.

Throughout our work on the 200-inch telescope, we have had the advantage of testing all auxiliary apparatus with the telescopes on Mount Wilson. Reciprocally, the Mount Wilson Observatory has had the immediate use of the various new devices developed in the 200-inch telescope project. In this way both the California Institute and the Mount Wilson Observatory have profited greatly. In the present case it was thought wisest to begin the experiment by devising a correcting lens for the 60-inch Mount Wilson reflector.

The only aberration of outstanding significance in the focal plane of a paraboloidal mirror is coma, which is directly proportional to the radius of the field and the square of the aperture ratio of the mirror. Dr. Ross finds that a series of lenses may be designed for correcting coma, involving a loss of light of about 0.25 mag., slightly more than that produced by the silvered surface of a Newtonian flat.

The correcting lens made by Fecker for the 60-inch reflector is of 8-inch aperture, and is mounted 15 inches from the Newtonian focus. It is only approximately of zero power, as it increases the focal length of the mirror by 4.4 inches, or 1.4 per cent. This involves a displacement outward of the focal point by 2.7 inches. The enlargement of the field of good definition is very striking, as is shown by a comparison of the star images at a distance of 27′ from the axis of the 60-inch reflector as photographed with and without the correcting lens.[5] A similar correcting lens was also designed by Ross for the 100-inch telescope, and constructed in the Optical Shop of the Mount Wilson Observatory.

As both of these lenses give excellent results, Dr. Ross has designed two separate correcting lenses for the 200-inch telescope. Both of these will remove coma and thus render possible measures of the highest precision in photographic photometry and the determination of star positions. The first will have a spherical aberration confusion disk 1″.5 in diameter for use under the best conditions of seeing, when it should increase the area of the field at the principal focus of the 200-inch mirror about tenfold. The second, for use under less perfect conditions, will have a confusion disk of 2″.5, and will increase the area of the useful field from twenty to thirty times.[6]

*Rayton lens.*—Prior to the initiation of the 200-inch telescope project, a large number of short-focus camera objectives were tried in the spectrograph used with the 100-inch telescope to determine the radial velocities of extra-galactic nebulae. Good results were obtained with some of these lenses, but it was our hope that lenses of still shorter focal length could be designed. Dr. W. B. Rayton, of the Bausch and Lomb Optical Company, was therefore requested to make a special study of the problem.

After the completion of a lens having a speed of $f/2.4$, which gave good results with the 100-inch telescope, a lens of the type of a 4-mm microscope objective was designed by Dr. Rayton at the suggestion of Dr. Anderson. This has an equivalent focus of 32 mm and a rela-

[5] Ross, "Astrometry with Mirrors and Lenses," *Ap. J.*, **77**, 243, Pl. VII, 1933; *Mt. W. Contr.*, No. 467.

[6] Ross, "The Optics of Reflecting Telescopes," *Pub. A.S.P.*, **46**, 339, 1934; "Lens Systems for Correcting Coma of Mirrors," *Ap. J.*, **81**, 156, 1935.

tive aperture of $f/0.59$. When substituted by Mr. Humason for the fastest lens previously obtainable for the nebular spectrograph of the 100-inch telescope, it was found to show excellent definition and a great gain in speed.[7] It is with this lens that the extremely high radial velocities of the very remote nebulae have been determined by Mr. Humason, leading to the deduction by Dr. Hubble of the linear relationship between velocity and distance of the extra-galactic nebulae ("the expansion of the universe").[8]

*B.S.I.R.A. lens.*—Subsequently I took up the same problem with Sir Herbert Jackson, then director of the British Scientific Instrument Research Association. At his suggestion Mr. R. J. Bracey, a member of his staff, has successfully calculated an immersion objective of the extraordinary ratio of $f/0.35$. With the continued cooperation of Dr. Harry Moore, Sir Herbert Jackson's successor, this lens has recently been completed for us by Messrs. R. and J. Beck, Limited, of London. The rest of the optical system of the spectrograph (two prisms and a collimator lens) were made by Messrs. Ross, Limited, and the entire combination has been satisfactorily tested at the laboratory of the Research Association in London. In this unique objective the focus is on the plane surface of the rear lens of the system, with which the plate is kept in optical contact by a special immersion fluid. As the laboratory tests were successful, the optical parts were sent to Pasadena, where the spectrograph to carry them is now under construction in our Instrument Shop. It will soon be tested on nebulae, in combination with the 100-inch telescope.

*Photo-electric amplifier.*—At the beginning of this general study of auxiliary instruments an arrangement was made with Dr. Joel

[7] Rayton, "Two High-Speed Camera Objectives for Astronomical Spectrographs," *Ap. J.*, **72**, 59, 1930.

[8] See various papers in this *Journal* by Humason and Hubble. In actual practice, a twelfth (photographic) magnitude star, which formerly required an exposure of about two hours with two prisms, can now be secured in ten minutes. On faint nebulae exposures of twelve hours have been reduced to about one-eighth of this time. The increased slit width, possible because of the shorter focal length of the Rayton lens, is, of course, an important factor. Some valuable experiments have also been made with a single Zeiss lens very kindly loaned by Lord Rayleigh. It was formerly used by him in photographing the spectrum of the aurora.

Stebbins to push his development of the photo-electric cell to the farthest attainable limits. His long experience with cells best suited for astrophysical investigations was a great advantage, but at first he was unable to improve materially the excellent equipment he was already using. Dr. Albert E. Whitford, an advanced student working in the University of Wisconsin in co-operation with Dr. Stebbins, subsequently succeeded in constructing a photo-electric cell, mounted *in vacuo* with a special amplifier, with which Dr. Stebbins has secured remarkable results on Mount Wilson. By actual test, without a telescope, this amplifier easily shows a candle 7 miles away—farther than it can be seen by the eye. This in spite of the absorption of the intervening air. With the 100-inch reflector the limit of detection of a candle would be 3,000 miles, assuming no absorption in the atmosphere beyond the first mile.

As an illustration of Dr. Stebbins' recent work, which was done with the assistance of Dr. Whitford, reference may be made to a paper on the diameter of the Andromeda Nebula, showing its length and breadth to be at least double that previously known.[9] Dr. Stebbins has applied this photo-electric amplifier to many other important uses, which show how greatly it will increase the efficiency of the 200-inch telescope. This advance is especially striking to the writer, who used an Elster and Geitel photo-electric cell in spectroscopic work at the University of Berlin in the winter of 1893–1894, in association with Dr. H. M. Goodwin.

Dr. Sinclair Smith, a member of the Mount Wilson Observatory staff who has devoted part of his time to the 200-inch project, has made extensive studies of various auxiliary instruments and methods, including the photo-electric cell and the radiometer. A paper assigning a lower limit to the useful sensitivity of the photo-electric cell should be mentioned in the present connection.[10]

After the completion of the designs of the 200-inch telescope

[9] Stebbins and Whitford, "The Diameter of the Andromeda Nebula," *Mt. Wilson Comm.*, No. 113; *Proc. N.A.S.*, **20**, 93, 1934. An important application of this amplifier is described in Stebbins' article on "The Dark Galaxy" in the *Pop. Sc. Mo.* for August, 1934.

[10] Smith, "The Limiting Magnitude Observable with a Photo-electric Stellar Photometer," *Ap. J.*, **76**, 286, 1932; *Mt. Wilson Contr.*, No. 457.

mounting and the Observatory buildings, they will be described and illustrated in this *Journal*.

I cannot close this paper without reference to the invaluable aid received from the officers of the General Education Board and the Rockefeller Foundation. They are most generous in giving their time and thought to technical problems, both financial and scientific, whenever they are brought before them. In connection with the 200-inch mirror disk and the design of the telescope mounting, President Mason's long experience as a physicist has been of great value. As a trustee of the California Institute and a member of the Mount Wilson Observatory of the Carnegie Institution of Washington, I gratefully appreciate that the cordial co-operation of all of these institutions made this project possible.

PASADENA, CALIFORNIA
March 1935

# TEMPERATURE CLASSIFICATION OF SAMARIUM LINES*

By ARTHUR S. KING

ABSTRACT

A temperature classification is given for 4477 samarium lines between λ 2900 and λ 8700. About 2800 of these belong to *Sa* I and 442 fall into classes I and II, furnishing the basis for a term analysis. As with other rare earths, the furnace was highly effective in developing lines of the neutral spectrum, many of which are faint in the arc, and also gave the more sensitive lines of *Sa* II, recognized through the comparison of furnace spectra with those of the arc and spark. Wave-lengths of the neutral lines were measured in the furnace, a large proportion being new, and a checking of the earlier measures of *Sa* II resulted in improved values in many cases, especially when close blends with neutral lines occur. In the arc, the relative strengths of the *Sa* I and *Sa* II spectra appeared to depend on the intensity of vaporization, governing the frequency of ionic combination. A strong ultra-violet spectrum peculiar to the spark probably arises from *Sa* III.

The doublet structure of many samarium lines, especially those of *Sa* II, is described and measurements are given for the lines most clearly resolved. The explanation of this effect, probably a combination of isotope displacement and hyperfine structure, must await examination under high resolution.

The classification of samarium lines according to their response to various degrees of excitation follows the plan of previous papers on rare-earth spectra.[1] The study, in which the spectra of the electric furnace at three temperature stages were compared with those of the arc and spark, gave incidentally a selection of the lines due to ionized samarium and showed the relative response of these, the lines of astrophysical importance, to increasing excitation.

The spectrograms were made with the 15-foot concave-grating spectrograph, the second order (scale, 1 mm = 1.86 A) being used to the violet of λ 5400. This region was covered in the brighter first order as well for the low-temperature spectrum.

The tube furnace, charged with samarium in the form of either the sulphate or the oxalate, was operated at temperatures near 2600°, 2300°, and 2000° C for the high, medium, and low tempera-

* *Contributions from the Mount Wilson Observatory, Carnegie Institution of Washington*, No. 523.

[1] *Mt. W. Contr.*, No. 368; *Ap. J.*, **68**, 194, 1928; *Mt. W. Contr.* No., 414; *Ap. J.*, **72**, 221, 1930; *Mt. W. Contr.*, No. 439; *Ap. J.*, **74**, 328, 1931; *Mt. W. Contr.*, No. 470; *Ap. J.*, **78**, 9, 1933.

tures, respectively. The more persistent lines, appearing at 2000°, are included in classes I and II, those of class I undergoing least change at the higher temperatures. At 2300° the lines of class III appear, and this temperature gave nearly all the stronger lines of neutral samarium. Class IV lines, faint at 2300°, are distinct at 2600°. Class V lines, appearing only in the arc, are relatively few in this spectrum, being chiefly in the infra-red. In the ultra-violet, most of the furnace lines which appear are necessarily placed in class IV (lines of class III beginning at λ 3250), since the highest furnace temperatures are required to produce an emission spectrum in this region. These lines may, however, according to experience with other spectra, be regarded as probably arising from low atomic levels.

The arc spectrum of samarium resembles the arc spectra of other rare earths in being made up largely of lines of the ionized atom, especially at shorter wave-lengths. The selection of these *Sa* II lines was based on their faintness in the furnace and their prominence in the spark, and was checked by occasional furnace runs in which caesium was mixed with the samarium. The large supply of free electrons from caesium resulted in recombination of the ionized samarium and a disappearance of the enhanced lines. In the arc, the strength of the neutral spectrum appeared to depend largely on the amount of material being vaporized. It was found that a moderate supply of samarium, enough to color the arc flame, gave a spectrum with the *Sa* II lines prominent. In fact, an almost pure *Sa* II spectrum, having practically no resemblance to that of the furnace, could be obtained in this way. The governing conditions evidently were vigorous ionization and little opportunity for recombination. When, however, a large supply of samarium compound was placed in the carbon arc, and this allowed to burn, often for several minutes, until strong vaporization of the samarium took place, the arc image then being rose pink, the *Sa* I lines were comparable in strength with those of *Sa* II. This should result from the increased combination possibilities. In consequence, the relative intensities of the neutral and ionized spectra vary from plate to plate, and consistent intensity values of individual lines can be given only for those of each spectrum by itself.

The spark spectrum, for which either graphite or silver electrodes

charged with samarium were used, showed a clear intensification of the *Sa* II lines when compared with the arc spectrum. In the infra-red, the spark radiation as a whole is weak, and some lines which are faint in the arc and were not obtained in either spark or furnace are questioned as to their identity with *Sa* II.

Although wave-length determinations were not the primary object of this study, the desirability of a list adequate for both identification and term analysis led to measurements by the writer, with the assistance of Miss Brayton, of a large proportion of the lines given, especially those of *Sa* I. Extensive lists of samarium lines have been published by Rütten and Morsch,[2] Exner and Haschek,[3] Eder,[4] and Kiess.[5] Wave-lengths of the first two require conversion from the Rowland system; the list of Kiess is for wave-lengths greater than λ 5472. The converted values of Rütten and Morsch, being to three decimal places and obtained from spectra taken with a large grating, were adopted for many of the stronger lines of shorter wave-length, but were checked in large part by the writer. In the green, poor agreement between the earlier measures and those of the writer, perhaps on account of the improved iron standards now available, caused a general revision of the wave-lengths in this region.

For wave-lengths greater than λ 5370, the values, to two decimal places only, are in part the arc measures of Kiess for *Sa* II and in part those of the writer for the furnace lines. The slightly larger scale of the present plates, together with the sharpness of furnace lines, permitted the resolution of many close pairs and the detection, by comparing arc and furnace spectrograms, of near coincidences of lines of *Sa* I and *Sa* II.

In the ultra-violet, lines of *Sa* II fainter than intensity 10 are usually not included in the table. Few of these have been measured by anyone, and a thorough study of *Sa* II should extend much farther into the ultra-violet than does the present list beginning at λ 2900, which is the limit for emission furnace lines. A number of ultra-violet lines in class V E are noted as especially strong in the spark as compared with the arc. These may be high-level lines of *Sa* II or

[2] *Zs. f. wiss. Phot.*, **3**, 181, 1905. [3] *Spektren der Elemente*, **2**, 1911.

[4] *Sitz. Wien Akad.*, IIa, **125**, 883, 1916.

[5] *Sci. Papers Bur. Stand.*, **18**, 201 (No. 442), 1922.

low-level lines of *Sa* III, a matter requiring further investigation. The spark at wave-lengths below λ 3200 shows a great number of lines, often strong, which are absent in the arc and in all probability form the spectrum of *Sa* III.

As with other rare earths and elements such as vanadium, of medium ionization potential, the stronger lines of *Sa* II may appear in the furnace, often at 2300° (when they are placed in class III E), and their relative energy levels are indicated by their strength at this moderate excitation. In the red and beyond, *Sa* II lines become increasingly difficult to produce in the furnace, although spectrograms at 2700° and 2800° showed traces of the stronger ones.

Low-temperature lines are distributed throughout the spectrum; those of classes I and II, by the use of which Albertson[6] has made a very successful start on the term analysis, number 442. As has been noted, other furnace lines of shorter wave-length probably arise from low levels. The remaining lines of *Sa* I go, with few exceptions, into classes III and IV. Lines relatively faint in the arc (I A, etc.) are found in all classes.

A feature of special interest in the samarium spectrum is the large number of lines of doublet structure. These doublets are variable as to magnitude of separation and to some extent as to the relative intensity of components. The displacement varies from barely perceptible widening to clear resolution, even in the first-order spectrum. The relative intensities of violet and red components are usually near 3:2, but sometimes 2:1, and in other cases approximately equal. Conspicuous doubling is much more common for lines of *Sa* II than for those of *Sa* I, and while it is found for fainter lines throughout the spectrum, the best examples of strong double lines occur at longer wave-lengths. The fact that a large proportion of the stronger lines are reasonably sharp led the writer,[7] from an examination of preliminary spectrograms in the blue and violet, to include samarium among the even-numbered rare earths which have sharp lines, while the tendency of odd-numbered elements of this group (thulium being an apparent exception) is to show hyperfine structure.

[6] *Phys. Rev.*, **47**, 370, 1935.

[7] *Mt. W. Contr.*, No. 414; *Ap. J.*, **72**, 221, 1930.

The doubling of samarium lines, if due to hyperfine structure, would indicate a nuclear spin of one-half, but in view of the group of samarium isotopes observed last year by Aston,[8] the interpretation of the doubling as an isotope displacement must be considered. The masses of the isotopes and the percentages of abundance found by Aston are as follows:

| Mass | Percentage | Mass | Percentage |
|---|---|---|---|
| 144 | 3 | 150 | 5 |
| 147 | 17 | 152 | 26 |
| 148 | 14 | 154 | 20 |
| 149 | 15 | | |

The possibility is obvious that a line due to the two heavier isotopes, 152 and 154, displaced to the violet, accounts for the stronger component, while the red component is a blend of lines from the less abundant isotopes. A mixture of isotope displacement with true hyperfine structure due to the presence of odd isotopes 147 and 149 is to be expected, and should result in a somewhat blurred red component. Actually, all the doublets which have been resolved show the red component less sharp than the violet. The many sharp lines in the spectrum would be accounted for by the assumption that they show no isotope displacement.

An application of Aston's results to the samarium doublets has recently been made by Schüler and Schmidt.[9] The one line described by them, λ 5320.6, is a narrow doublet of *Sa* I. Their discussion of possibilities, as well as my observations of lines with wider separations, show the need of a study with high-resolution apparatus to distinguish between isotopes and nuclear moments as causes of the structure.

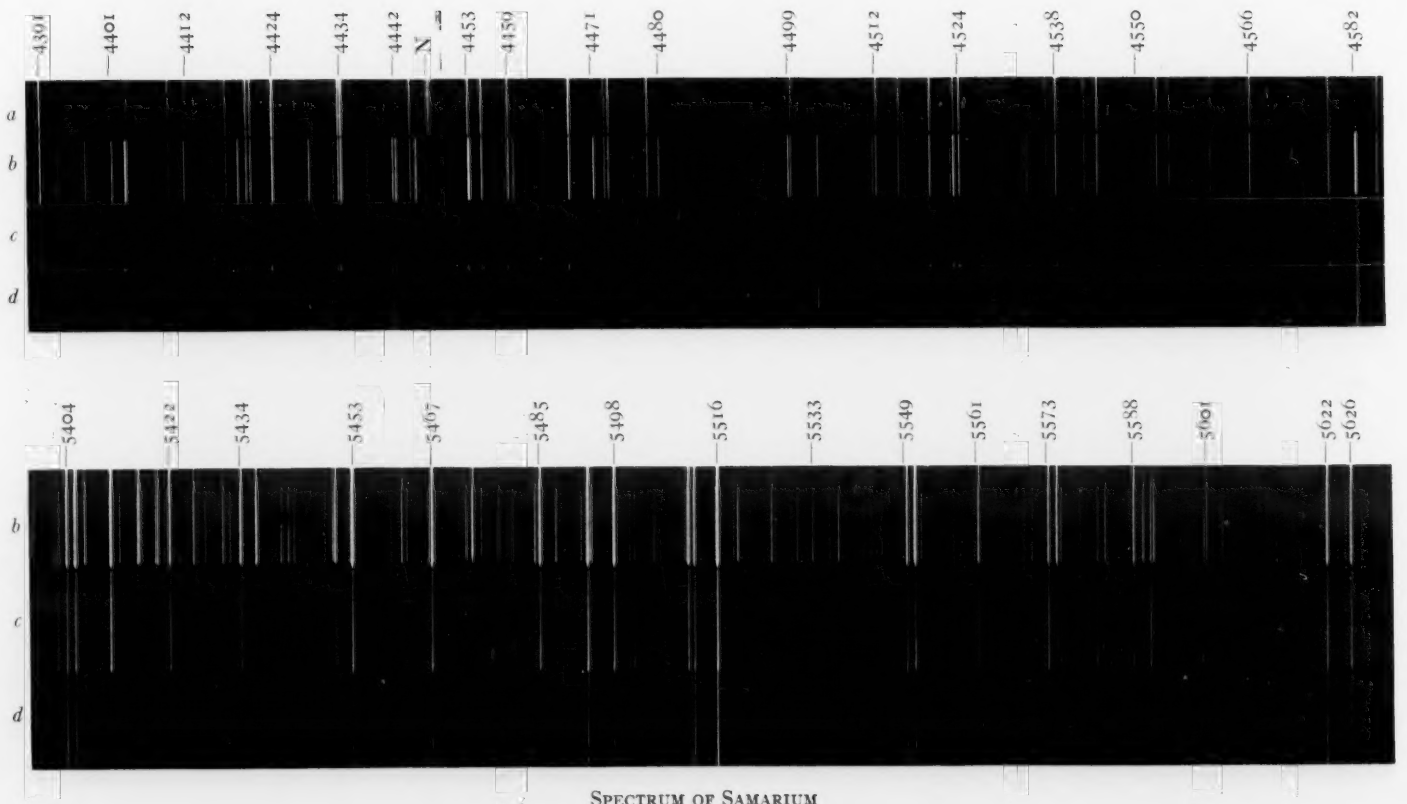
The accompanying list of doublets, which were measurable with tolerable accuracy on my plates, shows the general character of the phenomenon and indicates the lines favorable for a more detailed study of this structure. Separations in the deep red are about twice those in the green.

Plate XII shows spectra in the regions λλ 4391–4595 and λλ 5400–5630. In the first region the spark spectrum at the top gives the stronger lines of *Sa* II, which persist in the high-temperature furnace. The arc spectrum is made up of these and the neutral lines, selected

[8] *Proc. R. Soc.*, A, **146**, 46, 1934.

[9] *Zs. f. Phys.* **92**, 148, 1934.

# PLATE XII




SPECTRUM OF SAMARIUM

*a*) Spark; *b*) arc; *c*) furnace, 2600° C.; *d*) furnace, 2100° C.

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through their strength in the furnace and faintness in the spark. The region λλ 5400–5630 shows *Sa* I lines in much variety, including prominent low-temperature lines. *Sa* II lines in this section are for the most part faint.

| λ | Δλ(A) | Estimated Intensity Ratio | λ | Δλ(A) | Estimated Intensity Ratio |
|---|---|---|---|---|---|
| 5028.44..... | 0.086 | 3:2 | 6570.67..... | 0.16 | 1:1 |
| 5104.06..... | .078 | 2:1 | 6585.21..... | .14 | 1:1 |
| 5111.91..... | .080 | 3:2 | 6679.21..... | .16 | 4:3 |
| 5112.30..... | .074 | 3:2 | 6687.79..... | .186 | 1:1 |
| 5154.23..... | .087 | 1:1 | 6731.84..... | .17 | 3:2 |
| 5166.06..... | .089 | 2:1 | 6734.06..... | .18 | 4:3 |
| 5169.57..... | .099 | 1:1 | 6734.81..... | .20 | 4:3 |
| 5178.01..... | .091 | 3:2 | 6741.47..... | .156 | 4:3 |
| 5234.17..... | .099 | 4:3 | 6846.54..... | .167 | 3:2 |
| 5252.77..... | .091 | 4:3 | 6856.03..... | .163 | 5:4 |
| 5272.82..... | .086 | 1:1 | 6862.82..... | .157 | 5:4 |
| 5738.01..... | .117 | 2:1 | 6950.51..... | .195 | 4:3 |
| 5831.74..... | .126 | 4:3 | 6955.29..... | .156 | 3:2 |
| 6417.50..... | .14 | 3:2 | 7085.52..... | .186 | 4:3 |
| 6470.46..... | .15 | 2:1 | 7143.98..... | .179 | 3:2 |
| 6490.82..... | 0.15 | 3:2 | 7149.60..... | 0.179 | 3:2 |

*Explanation of the table.*—The classification of 4477 lines in Table I follows the plan adopted in previous papers on rare-earth spectra. The first column contains wave-lengths, of which some are for unresolved blends. When such a blend is made up of a neutral and an enhanced line, the wave-length of the former, measured in the furnace spectrum, is given, and for the *Sa* II line that of the arc blend, of which the enhanced component usually forms the major part. In the column of arc intensities, the estimated strength of the blend is entered. The more distinct cases of doubling, owing to isotope or hyperfine displacement, are indicated by "d" after the arc intensity. Of the furnace intensities, only that at high temperature is given, the behavior at lower temperatures being considered in assigning the class given in the final column. Lines of *Sa* II have "E" after the class number, and "A" is similarly placed for those neutral lines which are relatively much weaker in the arc than in the furnace. An asterisk (*) after the wave-length refers to a note at the end of the table; a dagger (†) after the wave-length indicates exceptional relative strength in the spark spectrum.

TABLE I

TEMPERATURE CLASSIFICATION OF SAMARIUM LINES

| λ | Intensity | | Class | λ | Intensity | | Class |
|---|---|---|---|---|---|---|---|
| | Arc | Furnace | | | Arc | Furnace | |
| 2910.275 | 100 | ..... | V E | 2969.025 | 30 | ..... | V E |
| 2911.278 | 20 | 1 | IV | 2969.958 | 15d | ..... | V E |
| 2911.719 | 25 | ..... | V E | 2970.483 | 8 | 1 | IV |
| 2912.564 | 20 | 1 | IV | 2970.926 | 20 | ..... | V E |
| 2914.712 | 20 | ..... | V E | 2974.920 | 10 | ..... | V E |
| 2917.386 | 15 | 1 | IV | 2976.512 | 8 | ..... | V E |
| 2917.630 | 15 | ..... | V E | 2977.070 | 20 | ..... | V E |
| 2919.264 | 10 | ..... | V E | 2981.327 | 15 | ..... | V E |
| 2920.603 | 6 | ..... | V E | 2982.894 | 6 | 1 | IV |
| 2920.828 | 10 | 1 | IV | 2983.432 | 40 | ..... | V E |
| 2921.314 | 10 | ..... | V E | 2984.996 | 10 | ..... | V E |
| 2921.425 | 10 | ..... | V E | 2985.245 | 8 | ..... | V E |
| 2922.821 | 10 | ..... | V E | 2987.653 | 30 | ..... | V E |
| 2924.681 | 20 | 1 | IV | 2988.409 | 4d | 1 | IV |
| 2926.654 | 25 | 2 | IV | 2988.849 | 10 | ..... | V E |
| 2927.106 | 30 | ..... | V E | 2988.925 | 10 | ..... | V E |
| 2927.607 | 15 | ..... | V E | 2991.574 | 40 | ..... | V E |
| 2927.745 | 10 | 1 | IV | 2992.521 | 6d | 2 | IV |
| 2928.258 | 15 | 1 | IV | 2992.916 | 12 | ..... | V E |
| 2928.800 | 8 | 1 | IV | 2993.828 | 20 | ..... | V E |
| 2929.452 | 5 | ..... | V E | 2994.203 | 4 | 1 | IV |
| 2932.056 | 10 | 1 | IV | 2995.160 | 4 | 1 | IV |
| 2933.064 | 6 | 1 | IV | 2995.874* | 6d | 1 | IV |
| 2933.548 | 5 | ..... | V E | 2996.475 | 10 | ..... | V E |
| 2935.413 | 5 | ..... | V | 2996.966 | 10 | ..... | V E |
| 2935.888 | 20 | ..... | V E | 2998.263 | 5 | 2 | IV |
| 2937.481 | 20 | ..... | V E | 3003.953 | 8 | ..... | V E |
| 2938.819 | 10 | ..... | V E | 3004.127 | 12 | ..... | V E |
| 2943.489 | 25 | ..... | V E | 3004.914 | 4d | 1 | IV |
| 2943.781 | 20 | ..... | V E | 3006.152 | 30 | ..... | V E |
| 2946.420 | 10 | 1 | IV | 3008.825 | 15 | ..... | V E |
| 2947.196 | 15 | ..... | V E | 3010.014 | 15 | ..... | V E |
| 2952.223 | 15 | ..... | V E | 3010.128 | 3 | 1 | IV |
| 2952.527 | 10 | ..... | V E | 3010.327 | 6 | 2 | IV |
| 2953.191 | 30 | ..... | V E | 3010.774 | 8d | ..... | V E |
| 2954.926 | 8d | ..... | V E | 3010.967 | 12 | ..... | V E |
| 2956.046 | 10 | ..... | V E | 3011.862 | 6 | 2 | IV |
| 2956.245 | 12 | ..... | V E | 3012.090 | 12 | ..... | V E |
| 2957.472 | 8 | ..... | V E | 3012.183 | 8 | 3 | IV |
| 2958.987 | 6 | ..... | V E | 3012.508 | 8 | ..... | V E |
| 2960.177 | 15 | ..... | V E | 3013.123 | 4 | 2 | IV |
| 2960.815 | 8 | ..... | V | 3013.396 | 6 | ..... | V E |
| 2961.323 | 6 | ..... | V | 3013.514 | 8 | 3 | IV |
| 2961.852 | 6 | ..... | V | 3014.053 | 15 | ..... | V E |
| 2961.971 | 8 | ..... | V E | 3014.368† | 12 | ..... | V E |
| 2962.032 | 5 | 1 | IV | 3015.075 | 2 | 2 | IV |
| 2962.742 | 10 | ..... | V E | 3015.689 | 10 | ..... | V E |

TABLE I—*Continued*

| λ | Intensity | | Class | λ | Intensity | | Class |
|---|---|---|---|---|---|---|---|
| | Arc | Furnace | | | Arc | Furnace | |
| 3016.075 | 5 | 2 | IV | 3065.777 | 80 | 1 | IV E |
| 3016.584 | 2 | 1 | IV | 3066.023 | 50 | ..... | V E |
| 3017.554 | 4 | 2 | IV | 3067.69 | 10 | ..... | V E |
| 3018.470 | 8 | ..... | V E | 3069.144 | 1 | 1 | IV |
| 3019.302 | 20 | ..... | V E | 3069.409 | 15 | 6 | IV |
| 3019.719 | 3 | 2 | IV | 3069.690 | 10 | ..... | V E |
| 3021.225 | 8 | 3 | IV | 3070.199 | 2 | 2 | IV |
| 3023.075 | 6 | 1 | IV | 3070.397 | 15 | ..... | V E |
| 3026.588 | 5 | 3 | IV | 3070.874 | 3 | 3 | IV |
| 3027.474 | 8 | 3 | IV | 3071.288 | 40 | 1 | IV E |
| 3028.009 | 5 | 1 | IV | 3072.637 | 4 | 3 | IV |
| 3028.475 | 15 | ..... | V E | 3073.915 | 8 | 5 | IV |
| 3031.502 | 15 | ..... | V E | 3075.309 | 3 | 3 | IV |
| 3032.862 | 30 | ..... | V E | 3076.499 | 15d | ..... | V E |
| 3033.393 | 2 | 1 | IV | 3076.717 | 15 | ..... | V E |
| 3034.165 | 20 | 1 | IV E | 3076.968 | 15 | ..... | V E |
| 3034.490 | 25 | ..... | V E | 3077.433 | 3 | 2 | IV |
| 3034.844 | 60 | ..... | V E | 3080.003 | 4 | 2 | IV |
| 3036.682 | 6 | 2 | IV | 3080.712 | 25 | 1 | IV E |
| 3037.684 | 20 | ..... | V E | 3082.260 | 2 | 2 | IV |
| 3037.943 | 15 | 1 | IV E | 3084.290 | 15 | ..... | V E |
| 3038.307 | 2 | 1 | IV | 3084.455 | 15 | ..... | V E |
| 3039.128 | 50 | 1 | IV E | 3084.769 | 2 | 1 | IV |
| 3039.354 | 20 | ..... | V E | 3084.907 | 3 | 1 | IV |
| 3039.705 | 1 | 1 | IV | 3085.017 | 6 | 3 | IV |
| 3040.380 | 3d | 3 | IV | 3085.283 | 1 | 1 | IV |
| 3041.817 | 3 | 2 | IV | 3085.791 | 4 | 3 | IV |
| 3043.528 | 2 | 2 | IV | 3086.447 | 25 | ..... | V E |
| 3044.704† | 5 | ..... | V E | 3086.736 | 1 | 1 | IV |
| 3045.759 | 2 | 2 | IV | 3086.867 | 2 | 2 | IV |
| 3046.514 | 4 | 3 | IV | 3087.382 | 20 | 1 | IV E |
| 3046.929 | 100 | 1 | IV E | 3087.930 | 15 | ..... | V E |
| 3047.254 | 2 | 2 | IV | 3088.184 | 8 | 5 | IV |
| 3047.360 | 15 | ..... | V E | 3088.821 | 3 | 4 | IV |
| 3047.937 | 1 | 1 | IV | 3088.985 | 20 | ..... | V E |
| 3050.80† | 6 | ..... | V E | 3089.625 | 4 | 3 | IV |
| 3051.02 | 30 | ..... | V E | 3090.442 | 10 | 8 | IV |
| 3051.657 | 2 | 2 | IV | | 15 | ..... | V E |
| 3053.634 | 6 | 5 | IV | 3092.316 | 3 | 3 | IV |
| 3054.313 | 2 | 2 | IV | 3094.665 | 4 | 4 | IV |
| 3055.272 | 15 | ..... | V E | 3095.480 | 10 | ..... | V E |
| 3055.521 | 10 | ..... | V E | 3095.718 | 15 | 2 | IV E |
| 3057.229 | 2 | 2 | IV | 3096.068 | 3 | 3 | IV |
| 3060.054 | 2 | 2 | IV | 3096.675 | 25 | 1 | IV E |
| 3060.656 | 3 | 2 | IV | 3096.879 | 40 | 1 | IV E |
| 3060.969 | 4 | 1 | IV | 3097.697 | 1 | 1 | IV |
| 3061.141 | 15 | 4 | IV | 3098.006 | 3 | 2 | IV |
| 3061.56 | 40 | ..... | V E | 3098.185* | 4d | 2 | IV |
| 3063.335 | 2 | 2 | IV | 3098.328 | 1 | 1 | IV |
| 3065.008 | 2 | 2 | IV | 3098.752 | 1 | 1 | IV |
| 3065.20 | 50 | ..... | V E | 3099.166 | 10 | ..... | V E |

TABLE I—*Continued*

| λ | Intensity | | Class | λ | Intensity | | Class |
|---|---|---|---|---|---|---|---|
| | Arc | Furnace | | | Arc | Furnace | |
| 3099.629 | 4 | 3 | IV | 3143.507 | 15 | ..... | V E |
| 3100.500 | 1 | 1 | IV | 3144.374 | 2d | 2 | IV |
| 3101.927 | 4 | 3 | IV | 3145.841 | 15 | ..... | V E |
| 3102.301 | 15 | 1 | V E | 3146.402 | 1 | 1 | IV |
| 3102.867 | 2 | 2 | IV | 3147.010 | 1 | 2 | IV A |
| 3103.226 | 4 | 3 | IV | 3147.191 | 60 | 2 | IV E |
| 3103.695 | 1 | 1 | IV | 3147.580 | 5 | 4 | IV |
| 3106.525 | 80 | 2 | IV E | 3148.817 | 4 | 5 | IV |
| 3107.529 | 10 | ..... | V E | 3149.027 | 1 | 2 | IV A |
| 3109.964 | 2 | 2 | IV | 3150.216 | 1 | 1 | IV |
| 3110.200 | 60 | 2 | IV E | 3150.338 | 2 | 1 | IV |
| 3111.753 | 2 | 2 | IV | 3150.661 | 1 | 2 | IV A |
| 3113.407 | 3 | 3 | IV | 3151.491 | 20 | 1 | IV E |
| 3113.496 | 1 | 1 | IV | 3152.096 | 50 | 2 | IV E |
| 3114.629 | 6 | 2 | IV | 3152.525 | 300 | 8 | IV E |
| 3114.782 | 12 | 5 | IV | 3154.359 | 10 | ..... | V E |
| 3115.049 | 25 | 1 | IV E | 3155.029 | 2 | 1 | IV |
| 3115.542 | 4 | 2 | IV | 3156.784 | 3 | 3 | IV |
| 3115.666 | 2 | 2 | IV | 3156.977 | 1 | 1 | IV |
| 3117.185 | 4 | 1 | IV | 3157.688 | 1 | 1 | IV |
| 3117.725 | 60 | 1 | IV E | 3157.842 | 20 | 1 | IV E |
| 3117.898 | 15 | ..... | V E | 3157.957 | 4 | 3 | IV |
| 3118.204 | 3 | 2 | IV | 3159.497 | 1 | 2 | IV A |
| 3118.862 | 2 | 2 | IV | 3160.267 | 2 | 2 | IV |
| 3120.254 | 2 | 2 | IV | 3160.522 | 3d | 3 | IV |
| 3121.417 | 1 | 1 | IV | 3160.887 | 15 | 1 | IV E |
| 3122.359 | 8 | ..... | V E | 3161.774 | 3 | 3 | IV |
| 3123.029 | 3 | 3 | IV | 3162.149 | 80 | 3 | IV E |
| 3123.907 | 2 | 2 | IV | 3162.299 | 100 | 3 | IV E |
| 3124.307 | 2 | 2 | IV | 3163.071 | 1 | 1 | IV |
| 3124.927 | 3 | 2 | IV | 3163.390 | 15 | 2 | IV E |
| 3126.002 | 8 | 2 | IV | 3163.721 | 2 | 2 | IV |
| 3127.161 | 15 | ..... | V E | 3163.905 | 1 | 1 | IV |
| 3128.864 | 1 | 2 | IV A | 3165.392 | 3d | 3 | IV |
| 3129.950 | 3d | 3 | IV | 3167.147 | 1 | 1 | IV |
| 3130.235 | 2 | 2 | IV | 3167.573 | 1 | 2 | IV A |
| 3131.759 | 1 | 1 | IV | 3169.624 | 1 | 2 | IV A |
| 3131.940 | 1 | 1 | IV | 3169.875 | 250 | 4 | IV E |
| 3132.288 | 1 | 1 | IV | 3170.208 | 100 | 2 | IV E |
| 3132.751 | 10 | 5 | IV | 3174.507 | 8 | 5 | IV |
| 3134.18 | 20 | ..... | V E | 3175.830 | 4 | 2 | IV |
| 3134.620 | 4 | 4 | IV | 3177.432 | 1 | 2 | IV A |
| 3135.985 | 2 | 2 | IV | 3177.748 | 3 | 3 | IV |
| 3136.298 | 200 | 5 | IV E | 3177.850 | 15 | ..... | V E |
| 3138.611 | 8 | 1 | IV E | 3178.125 | 200 | 4 | IV E |
| 3139.370 | 20 | 1 | IV E | 3178.450 | 15 | ..... | V E |
| 3139.974 | 100 | 3 | IV E | 3178.880 | 1 | 2 | IV A |
| 3140.385 | 20 | 1 | IV E | 3179.507 | 1 | 1 | IV |
| 3142.037 | 3 | 3 | IV | 3179.725 | 1 | 2 | IV A |
| 3142.794 | 3 | 4 | IV | 3180.305 | 12 | ..... | V E |
| 3143.299 | 60 | 1 | IV E | 3180.857 | 2 | 2 | IV |

TABLE I—*Continued*

| λ | Intensity | | Class | λ | Intensity | | Class |
|---|---|---|---|---|---|---|---|
| | Arc | Furnace | | | Arc | Furnace | |
| 3181.386 | 2 | 2 | IV | 3213.448 | 3 | 3 | IV |
| 3181.985 | 4 | 4 | IV | 3214.125 | 150 | 5 | IV E |
| 3182.623 | 4 | 3 | IV | 3214.613 | 2 | 4 | IV A |
| 3182.802 | 1 | 2 | IV A | 3215.262 | 200 | 6 | IV E |
| 3183.302 | 10 | ..... | V E | 3215.604 | 100 | 3 | IV E |
| 3183.916 | 400 | 8 | IV E | 3216.234 | 2 | 2 | IV |
| 3184.192 | 6 | 4 | IV | 3216.393 | 3 | 3 | IV |
| 3184.652 | 1 | 2 | IV A | 3216.850 | 300 | 12 | IV E |
| 3185.195 | 3 | 2 | IV | 3217.585 | 10 | 3 | IV |
| 3185.857 | 15 | ..... | V E | 3217.706 | 1 | 2 | IV A |
| 3186.025 | 80 | 2 | IV E | 3218.043 | 60 | 2 | IV E |
| 3186.283 | 25 | 1 | IV E | 3218.260 | 2 | 2 | IV |
| 3187.006 | 200 | 5 | IV E | 3218.614 | 300 | 12 | IV E |
| 3187.216 | 300 | 6 | IV E | 3219.041 | 3 | 4 | IV |
| 3187.566 | 5 | 3 | IV | 3219.428 | {60 | 3 | {IV E |
| 3187.787 | 200 | 5 | IV E | | {40 | | {IV E |
| 3188.128 | 1 | 1 | IV | 3219.867 | 60 | 2 | IV E |
| 3188.716 | 30 | 1 | IV E | 3220.646 | 3 | 4 | IV |
| 3189.447 | 1 | 1 | IV | 3221.630 | 2 | 2 | IV |
| 3189.572 | 10 | ..... | V E | 3222.170 | 2 | 3 | IV |
| 3190.584 | 4 | 4 | IV | 3223.332 | 50 | 2 | IV E |
| 3191.031 | 3 | 3 | IV | 3224.253 | 50 | 2 | IV E |
| 3191.470 | 4 | 3 | IV | 3225.058 | 1 | 1 | IV |
| 3192.012* | 10 | 2 | IV E | 3225.195 | 15 | 1 | IV E |
| 3192.127 | 1 | 2 | IV A | 3225.622 | 3 | 3 | IV |
| 3192.736 | 5 | 1 | IV | 3225.733 | 1 | 1 | IV |
| 3193.014 | 300 | 8 | IV E | 3225.934 | 60 | 2 | IV E |
| 3196.182 | 150 | 4 | IV E | 3226.855 | 200 | 6 | IV E |
| 3196.549 | 2 | 3 | IV | 3228.198 | 1 | 2 | IV A |
| 3196.885 | 1 | 1 | IV | 3228.496 | 150 | 3 | IV E |
| 3197.156 | 1 | 1 | IV | 3228.784 | 200 | 5 | IV E |
| 3199.233 | 1 | 1 | IV | 3229.605 | 20 | ..... | V E |
| 3199.596 | 4 | 3 | IV | 3230.559 | 400 | 20 | IV E |
| 3199.802 | 6 | 4 | IV | 3230.979 | 10 | ..... | V E |
| 3201.805* | 100d | 2 | IV E | 3231.031 | 6 | 6 | IV |
| 3202.201 | 3 | 4 | IV | 3231.528 | 200 | 10 | IV E |
| 3204.157 | 1 | 2 | IV A | 3231.952 | 100 | 5 | IV E |
| 3204.570 | 10 | 1 | IV E | 3232.489 | 6 | 6 | IV |
| 3204.903 | 100 | 3 | IV E | 3232.639 | 20 | 1 | IV E |
| 3205.550 | 1 | 2 | IV A | 3233.498 | 40 | 1 | IV E |
| 3205.636 | 6 | 1 | IV | 3233.681 | 200 | 8 | IV E |
| 3206.018* | 3d | 2 | IV | 3233.791 | 4 | 4 | IV |
| 3207.185 | 400 | 15 | IV E | 3234.069 | 2 | 2 | IV |
| 3208.169 | 100 | 3 | IV E | 3234.432 | 80 | 3 | IV E |
| 3209.726 | 4 | 5 | IV | 3234.850 | 1 | 3 | IV A |
| 3210.026 | 3 | 3 | IV | 3236.638 | 500 | 20 | IV E |
| 3210.816 | 15 | 1 | IV E | 3237.208 | 30 | 1 | IV E |
| 3211.227 | 1 | 2 | IV A | 3237.891 | 60 | 2 | IV E |
| 3211.734 | 400 | 15 | IV E | 3239.366 | 10 | 8 | IV |
| 3212.224 | 1 | 3 | IV A | 3239.657 | 300 | 10 | IV E |
| 3212.834 | 10 | ..... | V E | 3241.161 | 500 | 20 | IV E |

TABLE I—*Continued*

| λ | Intensity | | Class | λ | Intensity | | Class |
|---|---|---|---|---|---|---|---|
| | Arc | Furnace | | | Arc | Furnace | |
| 3241.586 | 100 | 4 | IV E | 3275.870 | 40 | 2 | IV E |
| 3242.043 | 100 | 3 | IV E | 3276.747 | 200 | 4 | IV E |
| 3242.493 | 20 | 1 | IV E | 3277.354 | 5 | 6 | III |
| 3244.686 | 100 | 4 | IV E | 3278.874 | 20 | 1 | IV E |
| 3245.171 | 15 | ..... | V E | 3279.154 | 1 | 2 | IV A |
| 3245.621 | 4 | 4 | IV | 3280.218 | 6 | 4 | IV |
| 3245.802 | {30<br>15} | 10 | {IV E<br>IV | 3280.844 | 200 | 8 | IV E |
| | | | | 3281.775 | 5 | 4 | IV |
| 3246.149 | 1 | 2 | IV A | 3283.417 | 3 | 3 | IV |
| 3246.861 | 20 | 1 | IV E | 3283.728 | 2 | 3 | IV |
| 3247.370 | 6 | 6 | IV | 3283.892 | 10 | 8 | III |
| 3248.134 | 50 | 3 | IV E | 3284.286 | 3 | 3 | IV |
| 3249.042 | 4 | 4 | IV | 3285.270 | 15 | 1 | IV E |
| 3249.747 | 200 | 8 | IV E | 3285.664 | 200 | 6 | IV E |
| 3249.892 | 30 | 1 | IV E | 3286.229 | 300 | 8 | IV E |
| 3250.372 | 200d | 4 | IV E | 3286.538 | 60 | 2 | IV E |
| 3251.138 | 4 | 3 | IV | 3287.693 | 2 | 3 | IV |
| 3252.648 | 20 | 8 | IV | 3288.444 | 4 | 5 | IV |
| 3253.015* | 40 | 4 | IV E | 3288.915 | 4 | 5 | IV |
| 3253.401 | 300 | 10 | IV E | 3290.285* | 60d | 6 | IV E |
| 3253.641 | 30 | 1 | IV E | 3290.390 | 100 | 4 | IV E |
| 3253.943 | 200 | 12 | III E | 3290.648 | 100 | 4 | IV E |
| 3254.285 | 40 | 1 | IV E | 3291.429 | 15 | 10 | III |
| 3254.377 | 500 | 20 | III E | 3293.366 | 100 | 5 | IV E |
| 3254.727 | 20 | 1 | IV E | 3293.526 | 10 | ..... | V E |
| 3254.778 | 15 | 1 | IV E | 3293.605 | 3 | 3 | IV |
| 3255.631 | 40 | 2 | IV E | 3293.799 | 15 | ..... | V E |
| 3255.842 | 15d | 1 | IV | 3294.189 | 4 | 4 | IV |
| 3256.109 | 1d | 3 | IV A | 3295.444 | 100d | 3 | IV E |
| 3258.254 | 60 | 3 | IV E | 3295.813 | 300 | 10 | IV E |
| 3259.418 | 4 | 5 | III | 3298.104 | 500 | 20 | III E |
| 3260.27 | 20 | ..... | V E | 3298.996 | 10 | 8 | III |
| 3260.680 | 1 | 3 | IV A | 3300.109 | 20 | 1 | IV E |
| 3262.276 | 100 | 4 | IV E | 3300.978* | 100 | 10 | IV E |
| 3262.579* | 4 | 1 | IV | 3301.678 | 100 | 5 | IV E |
| 3263.192 | 2 | 3 | IV | 3302.091 | 30 | 1 | IV E |
| 3264.137 | 10 | 10 | III | 3303.606 | 4 | 4 | IV |
| 3264.943 | 150 | 4 | IV E | 3304.523 | 200 | 8 | IV E |
| 3265.043 | 3 | 3 | IV | 3304.803 | 2 | 1 | IV |
| 3267.509 | 3 | 4 | IV | 3305.027 | 1 | 1 | IV |
| 3270.490 | 80 | 2 | IV E | 3305.185 | 200 | 5 | IV E |
| 3270.680 | 100 | 3 | IV E | 3305.434 | 2 | 2 | IV |
| 3271.226 | 20 | 1 | IV E | 3305.758 | 15 | 1 | IV E |
| 3272.477 | 50 | 2 | IV E | 3306.388 | {50?<br>500 | 2<br>15 | IV E<br>IV E |
| 3272.599 | 60 | 2 | IV E | | | | |
| 3272.807 | 200 | 5 | IV E | 3306.614 | 150 | 4 | IV E |
| 3273.045 | 1 | 3 | IV A | 3307.017 | 500 | 10 | IV E |
| 3273.325 | 40 | 1 | IV E | 3307.346 | 1 | 3 | IV A |
| 3273.483 | 500 | 20 | III E | 3308.092 | 8d | 1 | IV E |
| 3274.430 | 1 | 4 | IV A | 3308.464 | 12 | ..... | V E |
| 3275.744 | 3 | 4 | IV | 3308.546 | 2 | 3 | IV |

TABLE I—*Continued*

| λ | Intensity | | Class | λ | Intensity | | Class |
|---|---|---|---|---|---|---|---|
| | Arc | Furnace | | | Arc | Furnace | |
| 3308.938 | 20 | 2 | IV E | 3348.683 | 200 | 3 | IV E |
| 3309.518 | 150 | 5 | IV E | 3348.866 | 10 | ..... | V |
| 3309.885 | 1 | 3 | IV A | 3349.822 | 20 | 1— | IV E |
| 3310.327 | 15 | 1 | IV E | 3350.664 | 12 | 10 | III |
| 3310.661 | 500 | 15 | IV E | 3350.875 | 200 | 2 | IV E |
| 3312.415 | 400 | 10 | IV E | 3351.271 | 20 | ..... | V E |
| 3315.841 | 2 | 1 | IV | 3351.689 | 5 | 5 | IV |
| 3316.196 | 20 | 1 | IV E | 3352.727 | 6 | 8 | IV |
| 3316.579 | 300 | 5 | IV E | 3353.118 | 4 | 6 | IV |
| 3317.870 | 40 | 1 | IV E | 3353.760 | 1 | 2 | IV A |
| 3319.123 | 30 | 2 | IV E | 3354.185 | 150 | 2 | IV E |
| 3319.559 | 60 | 6 | IV E | 3354.30 | 40 | 1— | IV E |
| 3320.155 | 600d | 10 | IV E | 3354.721 | 80 | 1 | IV E |
| 3320.586 | 80 | 3 | IV E | 3356.52 | 1 | 4 | IV A |
| 3321.179 | 800 | 20 | IV E | 3358.267 | 15 | 1— | IV E |
| 3323.768 | 200 | 8 | IV E | 3358.562 | 3 | 5 | IV |
| 3324.022 | 3 | 4 | IV | 3360.646 | 30 | 1 | IV E |
| 3324.615 | 5 | 5 | IV | 3360.688 | 1 | 6 | IV A |
| 3324.872 | 2 | 4 | IV | 3360.938 | 4 | 6 | IV |
| 3325.258 | 300 | 10 | IV E | 3361.429 | 100 | 1 | IV E |
| 3325.475 | 150 | 4 | IV E | 3363.167* | 1 | 3 | IV A |
| 3326.334 | 1 | 3 | IV A | 3363.906 | 10 | 1— | IV E |
| 3326.984 | 3 | 4 | IV | 3364.744 | 4 | ..... | V E |
| 3327.885 | 200 | 6 | IV E | 3364.795 | 10 | 1— | IV E |
| 3328.924 | 30 | 1 | IV E | 3365.863 | 400 | 15 | III E |
| 3329.616 | 40 | 3 | IV E | 3365.961 | 50 | 1 | IV E |
| 3330.508 | 4 | 4 | IV | 3366.522 | 1 | 4 | IV A |
| 3331.074 | 6 | 6 | IV | 3367.267 | 100 | 2 | IV E |
| 3331.935 | 4 | 4 | IV | 3368.568 | 200 | 6 | IV E |
| 3332.697 | 30 | 1 | IV E | 3369.037 | 60 | 3 | IV E |
| 3333.045 | 4 | 4 | IV | 3369.455 | 200 | 6 | IV E |
| 3333.635 | 150 | 3 | IV E | 3370.587 | 100 | 3 | IV E |
| 3333.744 | 1 | 2 | IV A | 3371.013 | 30 | 1— | IV E |
| 3334.119 | 3 | 2 | IV | 3371.209 | 150 | 4 | IV E |
| 3334.683 | 2 | 3 | IV | 3373.722 | 1 | 1 | IV |
| 3335.033 | 60 | 2 | IV E | 3373.774 | 5 | ..... | V E |
| 3336.124 | 200 | 5 | IV E | 3376.246 | 1 | 2 | IV A |
| 3338.514 | 2 | 2 | IV | 3376.484 | 80 | 1 | IV E |
| 3338.864 | 8 | 8 | IV | 3376.817 | 15d | 10 | III |
| 3340.579 | 800 | 20 | III E | | | ..... | V E |
| 3341.428 | 50 | 2 | IV E | 3377.810 | 20 | 1— | IV E |
| 3341.835 | 10 | 10 | III | 3378.305 | 15 | ..... | V E |
| 3343.494 | 200 | 4 | IV E | 3378.544 | 20 | 1— | IV E |
| 3343.640* | 50d | 6 | IV E | 3380.690 | 15 | 1— | IV E |
| 3344.169 | 10 | ..... | V E | 3382.070 | 2 | 4 | IV A |
| 3344.353 | 200 | 4 | IV E | 3382.399 | 600 | 15 | III E |
| 3345.394* | 3 | 5 | IV | 3384.658 | 300 | 8 | III E |
| 3345.763 | 3 | 6 | IV A | 3384.857* | ? | 3 | IV |
| 3346.350 | 50 | 4 | IV E | 3385.017* | 1 | 6 | III A |
| 3346.907 | 40 | 1 | IV E | 3385.393 | 20 | 1 | IV E |
| 3347.298 | 150 | 2 | IV E | 3385.970 | 8 | 12 | III |

TABLE I—*Continued*

| λ | Intensity | | Class | λ | Intensity | | Class |
|---|---|---|---|---|---|---|---|
| | Arc | Furnace | | | Arc | Furnace | |
| 3386.609 | 15d | 15 | III | 3425.257 | 20 | ..... | V E |
| 3387.057 | 20 | 1— | IV E | 3425.304 | | 10 | III |
| 3387.658 | 80 | 1 | IV E | 3426.200 | 80 | 1 | IV E |
| 3388.179 | 1 | 3 | IV A | 3427.855 | 2 | 6 | IV A |
| 3389.325 | 200 | 4 | IV E | 3427.972 | 20 | 1 | IV E |
| 3391.024 | 3 | 5 | III | 3429.753 | 40 | 1 | IV E |
| 3391.110 | 60 | 1 | IV E | 3429.798 | 3 | 8 | III |
| 3391.906 | 3 | 6 | IV A | 3431.902 | 20 | 20 | III |
| 3394.815 | 5 | 6 | IV | 3432.639 | 4 | ..... | V E |
| 3395.802 | 5 | 8 | III | 3433.676 | 150 | 2 | IV E |
| 3396.187 | 250 | 6 | IV E | 3434.521 | 5 | 8 | III |
| 3397.164 | 3 | 5 | IV | 3435.148 | 3d | 8 | III A |
| 3397.760 | 80 | 2 | IV E | 3435.266 | 15d | 1— | IV E |
| 3399.690 | 15d | ..... | V E | 3436.133 | 8 | 10 | III |
| 3399.841 | 50d | ..... | V E | 3436.486 | 2 | 4 | IV A |
| 3401.278 | 2 | 4 | IV A | 3437.100 | 80 | 1 | IV E |
| 3402.464 | 500 | 8 | IV E | 3437.618 | 6 | ..... | V E |
| 3402.82 | 1 | 3 | IV A | 3438.061 | 100 | 2 | IV E |
| 3403.090 | 100 | 1 | IV E | 3438.757 | 2 | 5 | IV A |
| 3406.061 | 1 | 3 | IV A | 3438.982 | 20 | 10 | III |
| 3406.547 | 6d | 8 | III | | | 5 | III |
| 3408.049 | 4 | 6 | III | 3439.610 | 10 | 1 | IV E |
| 3408.587 | 100 | 1 | IV E | 3440.502 | 100 | 1 | IV E |
| 3408.676 | 400 | 6 | IV E | 3441.232 | 4 | 6 | III |
| 3410.037 | 20 | 12 | III | 3444.619 | 50 | 2 | IV E |
| 3410.286 | 20 | 10 | III | 3445.62 | 15 | ..... | V E |
| 3410.396 | 20d | 15 | III | 3446.58 | 1 | 4 | IV A |
| 3411.22 | 1 | 5 | IV A | 3447.790 | 20 | 15 | III |
| 3411.30 | 20 | 1— | IV E | 3448.726 | 1 | 4 | IV A |
| 3412.18 | 1 | 4 | IV A | 3448.868 | 15 | 12 | III |
| 3412.567 | 3 | 8 | III A | 3449.561 | 15 | ..... | V E |
| 3413.609 | 1 | 3 | IV A | 3451.533 | 2 | 6 | III A |
| 3413.905 | 40 | 1 | IV E | 3451.892 | 6 | 10 | III |
| 3414.959 | 30 | 1 | IV E | 3452.781 | 30 | 1 | IV E |
| 3416.023 | 20 | ..... | V E | 3453.040 | 3 | 3 | III |
| 3416.198 | 20 | 12 | III | 3453.232† | 8 | ..... | V E |
| 3416.880 | 2 | 6 | IV A | 3453.558 | 100 | 1 | V E |
| 3418.151 | 300 | 5 | IV E | 3454.784 | 50 | 20 | III |
| 3418.2 | 1 | 1 | IV | 3454.972 | 60 | ..... | V E |
| 3418.514 | 500 | 8 | IV E | 3456.126 | 15 | 1— | IV E |
| 3419.774 | 150 | 4 | IV E | 3457.788 | 1 | 2 | IV A |
| 3420.510* | 15 | 6 | IV | 3457.921 | 20 | 2 | IV E |
| 3421.304 | 5 | 8 | III | 3458.277 | 3 | 6 | III A |
| 3421.903 | 1 | 5 | IV A | 3459.203 | 60 | 1— | V E |
| 3422.067 | 20 | 12 | III | 3459.415 | 60 | 1 | IV E |
| 3422.192 | 15 | ..... | V E | 3460.63 | 15 | 1— | IV E |
| 3422.476 | 2 | 4 | IV A | 3461.138 | 150 | 4 | IV E |
| 3422.768* | 6 | 8 | III | 3461.225 | 2 | 3 | IV |
| 3422.819 | 6d | ..... | V E | 3462.693 | 30 | 1— | IV E |
| 3423.499 | 3 | 5 | III | 3463.197 | 10 | ..... | V E |
| 3424.780 | 50d | 2 | IV E | 3463.609 | 5 | 10 | III A |

TABLE I—*Continued*

| λ | Intensity | | Class | λ | Intensity | | Class |
|---|---|---|---|---|---|---|---|
| | Arc | Furnace | | | Arc | Furnace | |
| 3464.070 | 50 | 1 | IV E | 3501.238 | 10 | 1— | IV E |
| 3464.431 | 50 | 1 | IV E | 3502.848 | 2 | 6 | III A |
| 3465.466 | 60 | 30 | III | 3503.289 | 20 | 1 | IV E |
| 3466.739 | 10 | 10 | III | 3504.218† | 6d | ..... | V E |
| 3466.796 | 30 | 20 | III | 3506.846 | 80 | 1 | IV E |
| 3467.874 | 100 | 2 | IV E | 3507.094 | 20 | ..... | V E |
| 3469.927 | 5 | 8 | III | 3507.715 | 1 | 4 | III A |
| 3470.37 | 1 | 4 | IV A | 3508.690 | 5 | 12 | III A |
| 3471.135 | 30 | ..... | V E | 3509.102† | 15d | ..... | V E |
| 3471.291 | 30 | 10 | III | 3509.431 | 10 | 1— | IV E ? |
| 3471.550 | 2 | 4 | IV A | 3509.790 | 15 | ..... | V E |
| 3472.032 | 4 | 12 | III A | 3510.15 | 1 | 4 | III A |
| 3473.05 | 1 | 6 | IV A | 3510.37 | 1 | 2 | IV A |
| 3473.718 | 3 | 8 | III A | 3511.227 | 150 | 5 | III E |
| 3473.964 | 40 | 1— | V E | 3511.41 | 1d | 8 | III A |
| 3474.381 | 15 | 10 | III | 3511.598 | 20 | 1 | IV E |
| 3475.137 | 15 | 1 | IV E | 3512.64† | 5d | ..... | V E |
| 3477.11 | 1 | 5 | IV A | 3512.926† | 15d | ..... | V E |
| 3477.436 | 20 | 15 | III | 3513.062† | 12d | ..... | V E |
| 3478.445 | 3 | 8 | IV A | 3518.065 | 15 | 5 | III E |
| 3478.955 | 6d | 12 | III A | 3518.306 | 15 | 8 | III E |
| 3479.152 | 15 | 1— | IV E | 3518.663 | 4 | 8 | III A |
| 3479.526 | 60 | 1 | IV E | 3521.513 | 15 | 15 | III |
| 3480.256 | 80 | 1 | IV E | 3522.81 | 2 | 6 | III A |
| 3480.564 | 80 | 1 | IV E | 3523.064 | 20 | 1— | IV E |
| 3480.88 | 1 | 2 | IV A | 3523.123 | 20 | 1— | IV E |
| 3481.523* | 4 | 10 | III A | 3523.416 | 30 | 20 | III |
| 3482.703 | 20 | ..... | V E | 3524.108 | 2 | 6 | III A |
| 3482.828 | 10 | 12 | III | 3524.552 | 15 | ..... | V E |
| 3483.485 | 8 | 12 | III | 3525.089 | 3 | 8 | III A |
| 3484.014 | 3 | 10 | III A | 3525.514 | 20 | 1— | IV E |
| 3483.57 | 1 | 6 | III A | 3526.779 | 15 | 15 | III |
| 3484.72 | 2 | 8 | III A | 3526.904 | 20 | 1 | IV E |
| 3485.802 | 10 | ..... | V E | 3527.066 | 15 | 12 | III |
| 3487.3* | 1 | 5 | III A | 3530.003 | 20 | 10 | III |
| 3487.409 | 80 | 2 | IV E | 3530.07 | 1 | 4 | III A |
| 3487.612 | 4 | 8 | III A | 3530.600 | 150 | 4 | III E |
| 3489.049 | 4 | 6 | III | 3532.02 | 12 | ..... | V E |
| 3490.705 | 2 | 6 | III A | 3532.566 | 80 | 2 | IV E |
| 3491.040 | 6 | 8 | III | 3534.924 | 10 | ..... | V E |
| 3491.995 | 2 | 6 | III A | 3535.143 | 4 | 10 | III A |
| 3492.623 | 20 | 1 | IV E | 3535.653 | 150 | 4 | IV E |
| 3492.775† | 8d | ..... | V E | 3536.77† | 10 | ..... | V E |
| 3492.898 | 10 | 12 | III | 3536.901 | 20 | 1— | IV E |
| 3493.412 | 15 | ..... | V E | 3538.842 | 15 | 1— | IV E |
| 3493.609 | 80 | 3 | IV E | 3539.252 | 15 | 1— | IV E |
| 3494.826 | 8 | 8 | III | 3539.88 | 3d | 12 | III A |
| 3495.916 | 20 | 1 | IV E | 3540.525 | 4 | 5 | III |
| 3499.837 | 150 | 4 | IV E | 3541.390 | 30 | 15 | III |
| 3499.9 | 1 | 1 | IV | 3542.455 | 40 | 1 | IV E |
| 3500.539 | 100 | 2 | IV E | 3545.416 | 8 | 10 | III |

TABLE I—*Continued*

| λ | Intensity | | Class | λ | Intensity | | Class |
|---|---|---|---|---|---|---|---|
| | Arc | Furnace | | | Arc | Furnace | |
| 3546.818 | 4 | 8 | III A | 3601.251 | 15 | ..... | V E |
| 3550.216 | 50 | 40 | II | 3601.692 | 200 | 8 | III E |
| 3552.206 | 8 | 10 | III | 3601.984 | 15 | 1— | IV E |
| 3552.302 | 50 | 1 | IV E | 3603.50† | 5d | ..... | V E |
| 3554.150 | 100 | 2 | IV E | 3604.285 | 800 | 30 | III E |
| 3556.744 | 100 | 2 | IV E | 3604.714 | 4 | 8 | III A |
| 3557.377 | 80 | 3 | IV E | 3604.988 | 20 | 1— | IV E |
| 3557.470 | 30 | 6? | III | 3606.324 | 4 | 8 | III A |
| 3558.873 | 4 | 12 | II A | 3607.5 | 1 | 1 | IV |
| 3559.101 | 300d | 8 | III E | 3607.644 | 15 | 12 | III |
| 3560.271 | 50 | 1 | IV E | 3609.491 | 1200 | 20 | III E |
| 3561.589 | 100 | 2 | IV E | 3611.055 | 5 | 10 | III A |
| 3562.224 | 15d | 15 | II | 3612.429 | 20 | 2 | IV E |
| 3563.591 | 8 | 6 | III | 3613.528 | 20 | 1 | IV E |
| 3564.216 | 30 | 8 | III | 3613.587 | 30 | 1 | IV E |
| 3566.468 | 15 | 8 | III | 3613.910 | 1 | 4 | III A |
| 3566.836 | 150 | 10 | III E | 3615.240 | 40 | 2 | IV E |
| 3568.271 | 1500 | 20 | III E | 3618.531 | 4 | 6 | III |
| 3568.888 | 8 | ..... | V E | 3619.294 | 20 | 2 | IV E |
| 3569.477 | 4 | 6 | III | 3620.104 | 80 | 4 | III E |
| 3571.078 | 10 | ..... | V E | 3620.576 | 100 | 3 | IV E |
| 3571.785* | 5d | 8? | III | 3620.958† | 4d | ..... | V E |
| 3572.828 | 6 | ..... | V E ? | 3621.229 | 600 | 20 | III E |
| 3573.845 | 5 | 8 | III | 3622.504 | 100 | 3 | IV E |
| 3575.451 | 40 | 12 | III | 3622.64 | 2 | 2 | IV |
| 3577.789 | 150 | 5 | III E | 3623.316 | 200 | 6 | III E |
| 3580.590 | 6 | ..... | V E | 3624.414 | 8d | 15 | III A |
| 3580.941 | 200 | 8 | III E | 3625.225 | 2 | 3 | III |
| 3582.671 | 30 | 1? | IV E | 3626.500 | 30 | 1 | IV E |
| 3583.394 | 150 | 2? | IV E | 3627.014 | 400 | 10 | III E |
| 3584.259 | 100 | 2? | IV E | 3627.447† | 4 | ..... | V E |
| 3586.360 | 80 | 40 | III | 3627.971 | 100 | 4 | III E |
| 3587.459 | 60 | 1 | IV E | 3628.501 | 1 | 4 | III A |
| 3589.301* | 4d | 8? | III A | 3628.620 | 2 | 4 | III A |
| 3589.796 | 20 | 1? | IV E | 3628.970 | 2 | 6 | III A |
| 3591.679 | 1 | 4 | III A | 3629.120 | 8 | 8 | III |
| 3591.741 | 30 | ..... | V E | 3629.221 | 15 | ..... | V E |
| 3592.497* | ? | 6 | III A | 3629.480 | 80 | 40 | III |
| 3592.603 | 1500 | 15 | III E | 3630.674 | 80 | 1 | IV E |
| 3592.894 | 10 | 8 | III | 3630.849 | 4 | ..... | V E |
| 3593.397 | 25 | 1 | IV E | 3631.126 | 400 | 6 | III E |
| | 30 | 1 | IV E | 3634.290 | 1500d? | 40 | III E |
| 3593.730 | 30 | 1— | IV E | 3634.928 | 200 | 5 | III E |
| 3594.004 | 20 | 12 | III | 3636.057 | 40 | 1 | IV E |
| 3594.508 | 2 | 4 | III A | 3636.106 | 30 | 8 | III |
| 3594.99 | 6d | ..... | V E | 3636.221 | 40 | 1 | IV E |
| 3595.929 | 5 | 10 | III A | 3637.563 | 1 | 3 | III A |
| 3596.659 | 2 | 8 | III A | 3638.767 | 400 | 6 | IV E |
| 3596.85 | 1 | 1 | IV | 3639.275 | 50 | 1 | IV E |
| 3597.05 | 8d | 15 | III A | 3639.409† | 8d | ..... | V E |
| 3597.927 | 25d | ..... | V E | 3641.628 | 5 | 10 | III A |

TABLE I—*Continued*

| λ | Intensity | | Class | λ | Intensity | | Class |
|---|---|---|---|---|---|---|---|
| | Arc | Furnace | | | Arc | Furnace | |
| 3642.756 | 100 | 1 | IV E | 3677.793 | 200 | 4 | III E |
| 3643.710 | 4d | ..... | V E | 3678.081 | 20 | ..... | V E |
| 3643.997 | 30 | 15 | III | | | 4 | III |
| 3645.290 | 300 | 10 | III E | 3678.167† | 10d | ..... | V E |
| 3645.387 | 200 | 6 | III E | 3679.997 | 8 | 1 | IV E |
| 3645.789 | 10d | 15 | III | 3680.983* | 100d | 15 | III |
| 3645.899 | 50 | 1 | IV E | 3681.734 | 100 | 2 | IV E |
| 3646.007 | 15 | ..... | V E | 3682.068 | 10 | 1 | IV E |
| 3646.975 | 1 | 6 | III A | 3682.203 | 40 | 2 | IV E |
| 3647.289 | 20 | 1— | IV E | 3682.551* | 8d | ..... | V E |
| 3649.527 | 500 | 8 | III E | 3684.136 | 20 | 1 | IV E |
| 3650.188 | 200 | 4 | IV E | 3684.776 | 3 | 5 | III |
| 3650.998 | 150 | 2 | IV E | 3687.098 | 10 | ..... | V E |
| 3651.423 | 30d | 15 | III | 3687.878 | 200 | 20 | III |
| 3651.516* | 6d | 3 | III | 3688.129 | 30 | 10 | III |
| 3651.825 | 4 | 8 | III A | 3688.418* | 100 | 2 | IV E |
| 3652.220 | 8 | ..... | V E | 3688.870 | 4 | ..... | V E |
| 3653.113 | 8 | 8 | III | 3689.606 | 15 | 12 | III |
| 3653.462* | 10d | 4? | III | 3690.084 | 300 | 50 | III |
| 3654.857 | 50 | 2 | IV E | 3690.653 | 10d | 15 | III |
| 3655.538† | 5d | ..... | V | 3690.929 | 60 | 2 | IV E |
| 3655.76 | 25 | 1— | V | 3692.221 | 150 | 6 | IV E |
| 3656.221 | 200 | 5 | IV E | 3692.762 | 60 | 2 | IV E |
| 3657.312 | 100 | 15 | III | 3692.894 | 40 | 1 | IV E |
| 3659.618 | 80 | 3 | IV E | 3693.989 | 1200 | 12 | III E |
| 3659.864 | 8 | 1 | IV E | | | 6 | III |
| 3661.05 | 3d | 4 | III | 3694.305 | 150 | 2 | IV E |
| 3661.365 | 1000 | 20 | III E | 3694.814 | 10 | 10 | III |
| 3661.687 | 2 | 3 | IV | 3695.82 | 2 | 6 | III A |
| 3662.268 | 100 | 3 | IV E | 3699.037 | 2 | 2 | IV |
| 3662.693 | 200 | 5 | IV E | 3700.197† | 12d | ..... | V E |
| 3662.905 | 200 | 4 | IV E | 3700.432 | 1 | 8 | III A |
| 3664.011 | 4 | 6 | III | 3700.597 | 100 | 3 | IV E |
| 3665.377 | 8 | 8 | III | 3700.922 | 150 | 3 | IV E |
| 3666.265 | 20 | 10 | III | 3701.173 | 6 | ..... | V E |
| 3666.972 | 2 | 6 | III A | 3701.557 | 50 | 1 | IV E |
| 3667.541 | 4 | 3 | III | 3701.688 | 20d? | 20 | III |
| 3667.932 | 150d | ? | IV E | 3705.062 | 20 | 1 | IV E |
| | | 40 | III | 3705.995 | 1 | 10 | III A |
| 3668.170* | 6d | 4 | III | 3706.752 | 300 | 6 | III E |
| 3668.887 | 20 | 10 | III | 3706.979 | 200 | 5 | IV E |
| 3669.907 | 20 | 1 | IV E | 3707.167 | 100d | ? | IV E |
| 3670.517 | 40 | 1 | IV E | | | 30 | III |
| 3670.677 | 150 | 3 | III E | 3707.629 | 10 | 12 | III |
| 3670.840 | 1000 | 15 | III E | 3707.850 | 150 | 40 | III |
| 3672.225† | 8d | ..... | V E | 3708.410 | 200 | 8 | III E |
| 3674.068 | 100 | 4 | III E | 3708.654 | 300 | 12 | III E |
| 3674.345 | 8 | 6 | III | 3708.77 | 10 | 10 | III |
| 3675.115 | 10 | 8 | III | 3709.023 | 10 | 10 | III |
| 3676.855 | 50 | 3 | IV E | 3709.525 | 20 | 1 | IV E |
| 3677.248 | 15d | 20 | III | 3710.304 | 4d | ..... | V E |

TABLE I—*Continued*

| λ | Intensity | | Class | λ | Intensity | | Class |
|---|---|---|---|---|---|---|---|
| | Arc | Furnace | | | Arc | Furnace | |
| 3710.869 | 100 | 3 | III E | 3753.091 | 4 | ..... | V E |
| 3711.543 | 200 | 6 | III E | 3754.675 | 15 | 1 | IV E |
| 3712.109 | 100 | 4 | III E | 3754.861 | 60 | 3 | III E |
| 3712.764 | 200 | 6 | III E | 3755.276 | 200 | 8 | III E |
| 3716.780 | 2 | 8 | III A | 3755.352* | ? | 6 | III |
| 3718.702 | 25 | 1 | IV E | 3756.411 | 600 | ?<br>100R | IV E<br>II |
| 3718.877 | 500 | 10 | III E | | | | |
| 3719.300 | 3 | 6 | III A | 3756.532 | 80 | 8 | III E |
| 3719.451 | 3 | 6 | III A | 3757.529* | 300 | 30 | III E |
| 3720.574 | 30 | 1 | IV E | 3758.450 | 150 | 10 | III E |
| 3720.645 | 6 | 8 | III | 3758.968 | 200 | 8 | III E |
| 3721.028 | 150 | 50 | III | 3760.045 | 100 | 4 | III E |
| 3721.847 | 400 | 8 | III E | 3760.169 | 60 | 15 | III |
| 3722.026 | 60 | 40 | III | 3760.694 | 500 | 20 | III E |
| 3722.566 | 10 | 3 | IV | 3760.785* | ? | 6 | III |
| 3724.022 | 15 | 1 | IV E | 3761.144 | 6 | 10 | III |
| 3724.902* | 200 | 10 | III E | 3762.588 | 200 | 8 | III E |
| 3726.242 | 10 | ..... | V E | 3763.161 | 3 | 6 | III A |
| 3726.805 | 100 | 4 | IV E | 3764.370 | 300 | 15 | III E |
| 3727.377 | 15 | 1 | IV E | 3765.427 | 60 | 2 | IV E |
| 3728.162 | 50 | 20 | III | 3765.615 | 1 | 3 | IV A |
| 3728.469 | 400 | 15 | III E | 3765.752 | 1 | 3 | IV A |
| 3728.934 | 30 | 2 | IV E | 3766.923 | 20 | 20 | III |
| 3729.754* | 150 | ? | IV E | 3767.358 | 200 | 6 | IV E |
| 3730.737 | 100 | 25 | III | 3767.755 | 150 | 8 | III E |
| 3731.258 | 600 | 20 | III E | 3767.924 | 30 | 1 | IV E |
| 3735.980 | 500 | 15 | III E | 3768.311 | 25 | 15 | III |
| 3737.141 | 200 | 8? | III E | 3768.807 | 5 | 12 | III A |
| 3737.362 | 1 | 4 | III A | 3770.730 | 40 | 1 | IV E |
| 3737.475 | 100 | 4 | IV E | 3770.936 | 4 | 10 | III A |
| 3737.873 | 1 | 3 | III A | 3771.351 | 40 | 2 | IV E |
| 3738.272 | 60 | 2 | IV E | 3772.136 | 8d | 15 | III A |
| 3739.117 | 300 | 10 | III E | 3772.644 | 100 | 4 | IV E |
| 3739.197 | 200 | 5 | III E | 3773.331 | 150 | 8or | II |
| 3739.362* | 20 | 1? | IV E | 3773.422 | 50 | 2? | III E |
| 3739.42* | ? | 6 | III A | 3774.127 | 20 | 15 | III |
| 3739.993 | 3d | 8 | III A | 3774.294 | 150 | 2 | IV E |
| 3740.750 | 15 | 12 | III | 3774.678 | 150 | 5 | III E |
| 3741.288 | 300 | 10 | III E | 3775.459 | 10 | 15 | III |
| 3743.868 | 500 | 20 | III E | 3775.846 | 10 | 12 | III |
| 3745.465 | 100 | 8or | II | 3777.081 | 4d | ..... | V E |
| 3745.605 | 200d | 15 | III E | 3777.840 | 40 | 2 | IV E |
| 3747.360 | 20 | 15 | III | 3778.136 | 400 | 10 | III E |
| 3747.622 | 100 | 6 | III E | 3779.563 | 50 | 1 | IV E |
| 3747.747 | 20 | 12 | III | 3780.151 | 15 | 1 | IV E |
| 3748.15† | 4d | ..... | V E | 3780.763 | 200 | 15 | III E |
| 3748.521 | 100 | 8or | II | 3780.927 | 150 | 5 | IV E |
| 3748.627 | 40 | 3 | III E | 3781.330 | 1 | 5 | III A |
| 3750.665† | 8d | ..... | V E | 3782.149 | 10 | 10 | III |
| 3751.568 | 80 | 5 | IV E | 3782.425 | 40 | 6 | III E |
| 3753.027 | 6 | ..... | V E | 3782.683 | 80 | 20 | III |

TABLE I—*Continued*

| λ | Intensity | | Class | λ | Intensity | | Class |
|---|---|---|---|---|---|---|---|
| | Arc | Furnace | | | Arc | Furnace | |
| 3783.063 | 25 | 1 | IV E | 3833.828 | 200 | 8? | III E |
| 3783.355 | 60 | 2 | IV E | 3834.476 | 300 | 8or | II |
| 3783.804 | 30 | 20 | III | 3834.604* | 150 | ? | IV E |
| 3785.351 | 3d | ..... | V E | 3834.945 | 5 | 8 | III |
| 3787.203* | 100 | ? | III E | 3835.725 | 100d | 2 | III E |
| 3787.359 | 20d | 30 | III | 3838.941 | 200 | 4 | III E |
| 3788.125 | 400 | 15 | III E | 3840.450 | 150 | ? | IV E |
| 3791.277 | 100 | 1 | IV E | 3840.607 | 30 | 1 | IV E |
| 3791.839 | 6 | 10 | III | 3842.356 | 80 | 2 | IV E |
| 3792.025 | 150 | 3 | IV E | 3843.500 | 200 | 6? | IV E |
| 3793.160 | 10 | 10 | III | 3843.772 | 60 | 2 | IV E |
| 3793.334 | 4 | 10 | III A | 3844.498 | 30 | 1 | IV E |
| 3793.971 | 500 | 20 | III E | 3846.277 | 60 | 15 | II |
| 3797.283 | 150 | 2 | IV E | 3846.761 | 30 | 15 | II |
| 3797.730 | 600 | 8 | III E | 3847.511 | 150 | 5 | III E |
| 3799.542* | 300 | ? | III E | 3848.779* | 200d | ? | IV E |
| 3800.370 | 100 | 1 | IV E | 3851.880 | 150 | 6 | III E |
| 3800.887 | 400 | 12 | III E | 3853.295 | 200 | 50r? | II |
| 3802.416 | 6 | 8 | III | 3854.209 | 300 | 8 | III E |
| 3803.942 | 300 | 100R | II | 3854.556* | 150d | 10 | III E |
| 3805.190 | 12 | 1 | IV E | | | ? | II ? |
| 3805.626 | 200 | 4 | III E | 3854.938 | 8 | 1? | IV E ? |
| 3806.037 | 12 | ..... | V E | 3855.901 | 100 | 4? | III E |
| 3806.467 | 60 | 20 | III | 3857.339 | 8 | 8 | II |
| 3806.766 | 60 | 3 | III E | 3857.912* | 100 | ? | III E |
| 3807.922 | 80 | 8 | III E | 3858.517* | 80 | 40? | II |
| 3808.463 | 80 | 1 | IV E | 3858.737* | 200 | 100r? | II |
| 3809.752 | 50 | ? | IV E | 3860.140 | 100 | 30 | II |
| 3809.883 | 50 | 2? | III E | 3860.274 | 40 | 2 | IV E |
| 3809.954 | 100 | 30 | III | 3860.625* | 4d | 6? | III ? |
| 3810.433 | 100 | 2 | IV E | 3861.062* | 30 | ? | IV (?) E |
| 3810.973 | 5 | 8 | III | 3861.181* | 25 | ? | IV (?) E |
| 3812.067 | 150 | 10 | III E | 3861.592* | 15 | ? | IV (?) E |
| 3812.836 | 6 | 12 | III A | 3861.786* | 40 | ? | III ? |
| 3813.634 | 80 | 1 | IV E | 3862.054 | 150 | 4 | IV E |
| 3813.827 | 150 | 30 | III | 3862.232 | 80 | 2 | IV E |
| 3814.631* | 100 | ? | IV E | 3863.422 | 6d | ..... | V E |
| 3816.846 | 8 | 8 | III | 3863.896 | 2 | ..... | V E |
| 3818.363 | 80 | 20 | III | 3864.047* | 10 | ? | V E |
| 3821.832 | 60 | 3 | III E | 3865.236 | 80 | 2 | IV E |
| 3822.972* | 100 | 15? | III | 3865.687 | 12 | ..... | V E |
| 3824.175 | 200 | 5 | III E | 3867.635 | 8d | ..... | V E |
| 3824.536 | 40 | 3 | III E | 3870.884* | 20 | ? | IV E |
| 3824.811 | 8 | 8 | III | 3871.778 | 300 | 8 | III E |
| 3824.992 | 30 | ..... | V E | 3873.220 | 40 | 1 | IV E |
| 3826.202 | 400 | 12 | III E | 3873.471 | 4d | ..... | V E |
| 3826.562 | 40 | 1 | IV E | 3873.724 | 15 | 15 | II |
| 3828.047 | 80 | 3 | III E | 3874.388 | 8 | ..... | V E |
| 3830.293 | 200 | 5 | III E | 3875.193 | 100 | 2 | III E |
| 3831.501 | 400 | 6 | III E | 3875.545 | 200 | 5 | III E |
| 3832.808 | 150 | 20 | III | 3877.205 | 60 | 1 | IV E |

TABLE I—*Continued*

| λ | Intensity | | Class | λ | Intensity | | Class |
|---|---|---|---|---|---|---|---|
| | Arc | Furnace | | | Arc | Furnace | |
| 3877.486* | 200 | ? | II | 3929.559 | 5 | ..... | V E |
| 3880.766* | 150 | ? | IV (?) E | 3931.155 | 8 | ..... | V E |
| 3880.990* | 8 | ? | V E | 3932.968 | 30 | 1 | IV E |
| 3881.383* | 100 | ? | IV (?) E | 3933.583* | 100? | 5 | IV E |
| 3881.787 | 100 | 4 | IV (?) E | 3935.181 | 6d | ..... | V E |
| 3882.499* | 50 | ? | IV (?) E | 3935.463 | 1 | 4 | III A |
| 3882.870* | 6 | ? | V E | 3935.764 | 150 | 6 | III E |
| 3883.423* | ? | ? | V E | 3937.063 | 80 | 3 | IV E |
| 3883.805 | 20 | 1 | IV E | 3938.433 | 8 | 1— | IV E |
| 3883.987 | 20 | 8 | II | 3938.743 | 1 | 1 | III |
| 3885.286 | 1000 | 15 | III E | 3939.642 | 10 | 1 | IV E |
| 3885.906 | 40 | 1 | IV E | 3941.874 | 300 | 20 | III E |
| 3886.040 | 20d | 8 | II | 3943.239 | 200 | 15 | III E |
| 3887.112 | 15 | ..... | V E | 3945.252 | 1 | 8 | II A |
| 3889.157 | 20 | 1 | IV E | 3946.511 | 200 | 12 | III E |
| 3889.215 | 60 | 3 | III E | 3947.838 | 100 | 3 | IV E |
| 3890.080 | 200 | 6 | III E | 3948.113 | 300 | 15 | III E |
| 3891.210 | 100 | 4 | III E | 3949.849 | 4 | 10 | I A |
| 3891.955 | 8 | 8 | II | 3951.887 | 100 | 6or | I |
| 3894.053 | 100 | 5 | III E | 3954.200 | 15 | 2 | IV E |
| 3894.291* | 5 | 1 | IV | 3957.301 | 1 | 4 | III A |
| 3895.091† | 8d | ..... | V E | 3957.523 | 4 | ..... | V E |
| 3895.424 | 15 | 1— | IV E | 3958.721 | 15 | 1 | IV E |
| 3896.977 | 600 | 20 | III E | 3959.527 | 100 | 10 | III E |
| 3897.258 | 15 | 1— | IV E | 3960.501* | 1 | 8 | II A |
| 3900.888 | 50 | 4 | IV E | 3961.804 | 40 | 2 | IV E |
| 3901.046 | 3 | 4 | III | 3962.132 | 20 | 12 | I |
| 3902.323† | 15 | ..... | V E | 3962.241 | 15 | 1 | IV E |
| 3903.417 | 500 | 15 | III E | 3962.995 | 200d | 15 | III E |
| 3904.189 | 2 | 3 | III | 3963.239 | 1 | 4 | II A |
| 3906.808 | 20 | 1 | IV E | 3964.102 | 6 | ..... | V E |
| 3908.260 | 20 | 8 | II | 3964.882 | 2 | 15 | II A |
| 3909.946 | 50 | 12 | I | 3966.045 | 150 | 10 | III E |
| 3910.088 | 25 | 1— | IV E | 3966.144 | 1 | 3 | III A |
| 3910.920 | 15 | ..... | V E | 3966.338 | 10 | 1— | IV E |
| 3912.985 | 25 | 1 | IV E | 3967.676 | 60 | 3 | IV E |
| 3913.368† | 8d | ..... | V E | 3967.782 | 20 | 1— | IV E |
| 3913.616† | 15 | ..... | V E | 3968.110 | 1 | 4 | III A |
| 3916.365† | 6d | ..... | V E | 3970.528 | 200 | 15 | III E |
| 3917.442 | 200 | 10 | III E | 3971.397 | 300 | 15 | III E |
| 3917.959 | 1 | 3 | III A | 3972.272 | 1 | 8 | II A |
| 3918.624 | 40 | 4 | IV E | 3973.102 | 4 | ..... | V E |
| 3920.100 | 8 | 1— | IV E | 3974.449† | 15d | ..... | V E |
| 3922.054 | 80 | 4 | IV E | 3974.665 | 150 | 80R | I |
| 3922.397 | 800 | 20 | III E | 3975.221 | 20 | 3 | III E |
| 3922.697 | 30 | 2 | IV E | 3976.270 | 200 | 12 | III E |
| 3924.680 | 5 | 5 | II | 3976.430 | 200 | 12 | III E |
| 3925.216 | 400 | 6or | I | 3978.116 | 1 | 8 | II A |
| 3926.325 | 20 | 20 | II | 3978.244 | 5 | 10 | I A |
| 3927.420 | 3 | 3 | III | 3979.200 | 150 | 8 | III E |
| 3928.279 | 400 | 20 | III E | 3980.884† | 1 | ..... | V E |

TABLE I—*Continued*

| λ | Intensity | | Class | λ | Intensity | | Class |
|---|---|---|---|---|---|---|---|
| | Arc | Furnace | | | Arc | Furnace | |
| 3983.138 | 200 | 10 | III E | 4048.620 | 8d | ..... | V E |
| 3984.449 | 1 | ..... | V E | 4049.584 | 10 | 1 | IV E |
| 3985.995 | 20 | 4 | III E | 4049.808 | 60 | 12 | III E |
| 3986.21 | 4 | ..... | V E | 4050.628 | 10 | ..... | V E |
| 3986.682 | 150 | 10 | III E | 4051.822 | 1 | 6 | II A |
| 3986.903 | 40 | 3 | III E | 4052.296 | 2 | ..... | V E |
| 3987.066 | 4 | 1— | IV E | 4054.512 | 5 | 25 | II A |
| 3987.428 | 80 | 6 | III E | 4058.872 | 80 | 5 | III E |
| 3990.002 } | 300 | { ? | IV E | 4061.069 | 15 | ..... | V E |
| 3990.025 } | | { 50r | I | 4062.320 | 15d | 40 | II A |
| 3991.019 | 30 | 15 | I | 4063.539 | 150 | 20 | III E |
| 3993.308 | 200 | 15 | III E | 4064.315 | 60 | 4 | III E |
| 3995.593 | 5d | ..... | V E | 4064.576 | 300 | 25 | III E |
| 3998.350 | 40 | 15 | I | 4065.006 | 5 | ..... | V E |
| 4001.612 | 1 | 5 | II A | 4066.183 | 10 | 1 | III E |
| 4003.461 | 60 | 6 | III E | 4066.737 | 200 | 15 | III E |
| 4003.718 | 10 | 1 | III E | 4067.381 | 15 | 4 | IV E |
| 4004.259 | 6 | ..... | V E | 4068.334 | 100 | 10 | III E |
| 4006.602 | 40 | 5 | III E | 4069.751 | 1 | 8 | II A |
| 4006.824 | 15 | 2 | IV E | 4070.996 | 5 | ..... | V E |
| 4007.482 | 80 | 5 | III E | 4075.845 | 250 | 12 | III E |
| 4008.097 | 15 | 1 | III E | 4076.649 | 80 | 8 | III E |
| 4008.330 | 10 | 1— | IV E | 4076.862 | 20 | 3 | III E |
| 4009.397 | 3 | ..... | V E | 4079.834 | 20d | 40 | II A |
| 4011.733 | 10 | 1 | IV E | 4080.561 | 60 | 6 | III E |
| 4015.770 | 15 | 1— | IV E | 4081.968 | 15 | 1 | III E |
| 4016.004 | 1 | 4 | II A | 4082.600 | 100d | 8 | III E |
| 4016.111 | 2 | 4 | II A | 4083.235 | 15 | ..... | V E |
| 4018.543† | { 1 | ..... | V E | 4083.584 | 100 | 10 | III E |
| | { 3 | | | 4084.403 | 80 | 6 | III E |
| 4019.835 | 30 | 3 | III E | 4087.505 | 1 | 10 | II A |
| 4019.982 | 80 | 6 | III E | 4092.266 | 400 | 15 | III E |
| 4020.798 | 2 | ..... | V E | 4093.041 | 3 | ..... | V E |
| 4021.423 | 5 | ..... | V E | 4094.046 | 80 | 6 | IV E |
| 4022.731 | 20 | 4 | III E | 4098.966 | 4 | 1 | IV E |
| 4023.231 | 300 | 15 | III E | 4099.959 | 4 | 15 | II A |
| 4030.419 | 6 | ..... | V E | 4101.317 | 3 | 3 | III |
| 4032.977 | 30 | 5 | III E | 4104.127 | 60 | 8 | III E |
| 4035.110 | 250 | 10 | III E | 4106.284 | 1 | 8 | II A |
| 4037.105 | 30 | 3 | III E | 4106.620 | 60d | 3 | IV E |
| 4038.098 | 20 | 2 | IV E | 4107.277 | 60 | 6 | III E |
| 4041.675 | 200 | 12 | III E | 4107.387 | 200 | 8 | III E |
| 4042.723 | 200 | 15 | III E | 4107.795 | 8d | 2 | IV E |
| 4042.905 | 250 | 20 | III E | 4108.316 | 20 | 2 | IV E |
| 4043.370 | 6 | ..... | V E | 4109.405 | 150 | 8 | III E |
| 4044.106 | 20 | 2 | III E | 4110.193 | 30 | 2 | IV E |
| 4044.954 | 20d | ..... | V E | 4113.902 | 100 | 8 | III E |
| 4045.052 | 30 | 6 | III E | 4116.465 | 30 | 5 | III E |
| 4046.162 | 50d | 10 | III E | 4118.551 | 400 | 15 | III E |
| 4047.160 | 80 | 15 | III E | 4119.574 | 15 | 3 | IV E |
| 4047.352 | 15 | 3 | III E | 4121.358 | 80 | 8 | III E |

TABLE I—*Continued*

| λ | Intensity | | Class | λ | Intensity | | Class |
|---|---|---|---|---|---|---|---|
| | Arc | Furnace | | | Arc | Furnace | |
| 4121.542 | 20 | 4 | III E | 4202.915 | 60 | 6 | III E |
| 4122.506 | 30 | 6 | III E | 4203.051 | 125 | 10 | III E |
| 4123.956 | 150 | 8 | III E | 4204.818 | 4 | ..... | V E |
| 4125.233 | 5 | 20 | II A | 4205.381 | 4 | ..... | V E |
| 4125.851† | 2d | ..... | V E | 4205.779 | 40 | 40 | I |
| 4126.117 | 2 | 10 | II A | 4206.128 | 100 | 8 | III E |
| 4129.231 | 100 | 6 | III E | 4206.622 | 60 | 4 | III E |
| 4129.994 | 1 | 8 | II A | 4207.250 | 1 | 6 | II A |
| 4133.189 | 10 | 2 | III E | 4210.352 | 150 | 10 | III E |
| 4133.796 | 1 | 4 | II A | 4212.946 | 8 | ..... | V E |
| 4135.143 | 50 | 3 | IV E | 4213.046 | 4 | ..... | V E |
| 4135.505 | 10 | 20 | I A | 4213.943 | 2 | ..... | V E |
| 4138.734 | 3 | 12 | II A | 4218.632 | 10d | 50 | II A |
| 4138.969 | 5 | 1 | IV E | 4219.306 | 8d | 40 | I A |
| 4142.813 | 8 | —? | V E | 4220.142 | 50 | 4 | IV E |
| 4142.969 | 1 | 4 | II A | 4220.548 | 2 | 2 | III |
| 4145.239 | 20d | 30 | I | 4220.659 | 200 | 10 | III E |
| 4145.594 | 1 | 6 | I A | 4221.881 | 2 | ..... | V E |
| 4146.636 | 1 | 4 | I A | 4223.703 | 30 | 4 | IV E |
| 4146.748 | 40 | 4 | IV E | 4224.230 | 5 | 1 | IV E |
| 4147.710 | 80 | 6 | III E | 4225.328 | 400 | 20 | III E |
| 4147.974 | 1 | 6 | I A | 4226.178 | 50d | 60r | I |
| 4149.831 | 200 | 15 | III E | 4226.858 | 2 | 10 | II A |
| 4151.135 | 1 | 5 | I A | 4229.704 | 300 | 15 | III E |
| 4151.213 | 4 | 8 | I A | 4230.727 | 4 | 10 | I A |
| 4152.068 | 50 | 1 | IV E | 4234.104 | 1 | ..... | V E |
| 4152.209 | 200 | 12 | III E | 4234.573 | 200 | 10 | IV E |
| 4153.332 | 100 | 4 | IV E | 4235.879 | 2 | ..... | V E |
| 4155.217 | 100 | 6 | III E | 4236.587 | 8 | 2 | IV E |
| 4156.250* | 30d | ? | IV E | 4236.745 | 250 | 10 | III E |
| 4158.854 | 1 | 5 | II A | 4237.663 | 200 | 12 | III E |
| 4159.400 | 20 | 1 | IV E | 4240.450 | 6d | 40 | I A |
| 4159.512 | 20 | 2 | IV E | 4244.246 | 3 | 12 | I A |
| 4163.144 | 50 | 4 | III E | 4244.702 | 200 | 12 | III E |
| 4163.724 | 25 | 2 | IV E | 4245.184 | 30 | 5 | IV E |
| 4164.790 | 1 | 8 | II A | 4247.390 | 5 | 3 | IV E |
| 4165.537 | 2 | ..... | V E | 4248.392 | 1 | 4 | III A |
| 4166.337† | 5d | ..... | V E | 4249.550 | 30 | 6 | III E |
| 4169.478 | 200 | 15 | III E | 4251.782 | 40 | 8 | III E |
| 4171.569 | 80 | 5 | IV E | 4253.719 | 6 | 2 | IV E |
| 4174.429 | 30 | 3 | IV E | 4256.209 | 2 | 12 | III A |
| 4178.019 | 100d | 4 | IV E | 4256.393 | 400 | 30 | III E |
| 4181.102 | 80 | 6 | IV E | 4258.168 | 1 | 6 | III A |
| 4183.333 | 60 | 50r | I | 4258.575 | 30 | 4 | IV E |
| 4183.764 | 150 | 10 | III E | 4259.389 | 3 | 1 | IV E |
| 4188.128 | 200 | 8 | III E | 4262.677 | 300 | 20 | III E |
| 4191.927 | 80 | 6 | III E | 4265.075* | 100d | 15 | III E |
| 4192.162 | 50 | 5 | III E | 4265.231 | 2d | ..... | V E |
| 4197.895 | 8 | 1 | IV E | 4266.309 | 30 | 20 | I |
| 4199.452 | 60 | 4 | IV E | 4269.768 | 3 | 1 | IV E |
| 4201.221 | 4 | ..... | V E | 4270.733 | 10 | 3 | IV E |

TABLE I—*Continued*

| λ | Intensity | | Class | λ | Intensity | | Class |
|---|---|---|---|---|---|---|---|
| | Arc | Furnace | | | Arc | Furnace | |
| 4270.841 | 40d | 3 | IV E | 4336.137 | 150 | 125R | I |
| 4271.862 | 40d | 40 | I | 4336.775* | 4 | 4 | IV |
| 4272.008 | 8 | 1 | IV E | 4338.965 | 25d | 60 | I A |
| 4274.011 | 2 | 12 | II A | 4339.924 | 5 | 20 | II A |
| 4275.641 | 1 | 8 | III A | 4342.383 | 2 | ..... | V E |
| 4277.404 | 1 | 8 | III A | 4344.843 | 1 | 8 | III A |
| 4279.507 | 4 | 1 | IV E | 4345.858 | 150 | 15 | III E |
| 4279.678 | 200 | 12 | III E | 4346.494 | 4 | ..... | V E |
| 4279.747 | 40 | 5 | IV E | 4347.273 | 2 | ..... | V E |
| 4279.942 | 80 | 8 | III E | 4347.801 | 400 | 20 | III E |
| 4280.324 | 20 | 4 | IV E | 4350.465 | 300d | 20 | IV E |
| 4280.789 | 400 | 20 | III E | 4350.815 | 6 | 50 | I A |
| 4281.009 | 100 | 10 | III E | 4352.101 | 200 | 15 | IV E |
| 4282.208 | 100 | 100r | I | 4355.835 | 2d | 40 | I A |
| 4282.833 | 80 | 80r | I | 4357.896 | 2 | 40 | II A |
| 4283.500 | 80 | 80r | I | 4360.720 | 150 | 15 | III E |
| 4283.772 | 5 | 8 | I | 4361.070 | 40 | 4 | IV E |
| 4284.529 | 5 | 1 | IV E | 4362.040 | 300 | 15 | III E |
| 4285.496 | 200 | 10 | III E | 4362.409 | 2 | ..... | V E |
| 4286.640 | 100 | 5 | III E | 4362.912 | 150 | 150R | I |
| 4290.832 | 1— | 8 | II A | 4363.448 | 60 | 8 | IV E |
| 4291.615 | 3 | ..... | V E | 4364.052 | 2d | ..... | V E |
| 4292.182 | 150 | 10 | III E | 4365.38† | 1 | ..... | V E |
| 4293.743 | 4 | 15 | II A | 4365.954 | 4 | 25 | I A |
| 4295.741* | 15 | ? | IV E | 4368.031 | 150d | 10 | III E |
| 4296.743 | 300 | 300R | I | 4369.922 | 40 | 6 | III E |
| 4299.141 | 20d | 40 | I A | 4370.480 | 4 | ..... | V E |
| 4299.340 | 10 | 2 | IV E | 4371.502 | 1 | ..... | V E |
| 4301.275 | 8 | 15 | II A | 4372.445 | 1 | ..... | V E |
| 4302.580* | ? | 2 | III | 4373.462 | 100 | 8 | III E |
| 4304.945 | 80 | 4 | IV E | 4373.722 | 3 | ..... | V E |
| 4305.113 | 1 | 10 | II A | 4374.975 | 100 | 12 | III E |
| 4309.012 | 200 | 20 | III E | 4376.04 | 1 | ..... | V E |
| 4312.854 | 60 | 30 | I | 4378.236 | 150 | 8 | IV E |
| 4313.338* | 5 | 2 | IV E | 4380.423 | 100d | 100r | I |
| 4313.727 | 40 | 6 | IV E | 4381.257 | 1 | 8 | II A |
| 4313.871 | 3d | 30 | II A | 4384.292 | 80 | 5 | IV E |
| 4315.351 | 2 | ..... | V E | 4386.219 | 40d | 60 | I |
| 4315.378 | 6d | ..... | V E | 4388.99 | 1 | ..... | V E |
| 4317.418 | 1 | 8 | III A | 4390.858 | 600 | 30 | III E |
| 4318.936 | 500 | 30 | III E | 4391.35 | 2d | 4 | III A |
| 4319.530 | 100 | 100r | I | 4392.60 | 2 | ..... | V E |
| 4323.284 | 200 | 15 | III E | 4393.170 | 1 | 20 | II A |
| 4324.460 | 60d? | 60r | I | 4393.354 | 60 | 30 | II |
| 4325.163 | 2 | 30 | II A | 4396.75 | 2 | 1— | IV E |
| 4326.145 | 4 | 30 | II A | 4397.341 | 60d | 60 | I |
| 4327.514 | 6 | 1 | IV E | 4399.884 | 8 | 2 | IV E |
| 4329.016 | 400 | 25 | III E | 4401.174 | 100 | 60 | II |
| 4330.016 | 125 | 150R | I | 4403.06 | 30 | ? | IV E |
| 4331.447 | 40 | 50 | I | 4403.13 | 100 | 150R | I |
| 4334.153 | 400 | 20 | III E | 4403.360 | 100 | 15 | III E |

TABLE I—*Continued*

| λ | Intensity | | Class | λ | Intensity | | Class |
|---|---|---|---|---|---|---|---|
| | Arc | Furnace | | | Arc | Furnace | |
| 4405.224 | 1 | 8 | III A | 4484.83 | 2 | ..... | IV E |
| 4405.674 | 3 | 1 | IV E | 4484.909 | 2d | 2 | IV |
| 4407.521 | 5 | 1 | IV E | 4485.570 | 4 | 1— | IV E |
| 4409.332 | 100 | 15 | III E | 4486.30 | 2 | 1— | IV E |
| 4411.135 | 1— | 2 | III A | 4490.019 | 4 | 30 | II A |
| 4411.585 | 30 | 60r | I A | 4490.758 | 1— | 10 | II A |
| 4411.833 | 10 | 4 | IV E | 4492.298 | 1d | ..... | V E |
| 4417.583 | 60 | 8 | III E | 4495.136 | 3 | 1 | IV E |
| 4419.332 | 80 | 150R | I A | 4499.108 | 100 | 150R | I |
| 4420.526 | 200 | 20 | III E | 4499.475 | 125 | 15 | III E |
| 4421.138 | 200 | 20 | III E | 4500.028 | 1d | 2 | IV A |
| 4423.383 | 10 | 20 | I A | 4501.379 | 6 | 3 | IV E |
| 4424.339 | 600 | 50 | III E | 4503.378 | 80 | 125r | I |
| 4426.011* | 4 | —? | IV E | 4504.321 | 1— | 6 | II A |
| 4427.583 | 20 | 5 | IV E | 4505.051 | 30 | 6 | IV E |
| 4427.814 | 6 | 1 | IV E | 4511.327 | 40 | 40 | I |
| 4429.664 | 60 | 80r | I | 4511.829 | 200 | 20 | III E |
| 4433.076 | 15 | 30 | I A | 4515.094 | 150 | 15 | III E |
| 4433.344 | 3 | 50 | II A | 4517.271 | 2 | 1— | IV E |
| 4433.885 | 300 | 20 | III E | 4519.521 | 3 | 1 | IV E |
| 4434.323 | 400 | 40 | III E | 4519.633 | 200 | 25 | III E |
| 4441.812 | 100 | 150R | I | 4520.905 | 1 | 1— | IV E |
| 4442.276 | 80 | 100r | I | 4522.546* | 20? | 30 | I |
| 4442.51 | 10 | 1 | IV E | 4523.037 | 150 | 20 | III E |
| 4443.270 | 6 | 15 | I A | 4523.182 | 30 | 30 | I |
| 4444.259 | 150 | 10 | IV E | 4523.912 | 250 | 20 | III E |
| 4445.153 | 80 | 125r | I | 4527.418 | 5 | 15 | I A |
| 4445.881* | 4 | 8 | III A | 4532.444 | 8d | 40 | I A |
| 4446.955 | 5 | 1 | IV E | 4533.799 | 50 | 50 | I |
| 4452.727 | 250 | 20 | III E | 4534.869 | 1 | 20 | I A |
| 4452.953 | 60 | 50 | I | 4536.161 | 1 | 20 | I A |
| 4454.629 | 200 | 15 | III E | 4536.514 | 60 | 10 | IV E |
| 4456.110 | 6 | 2 | IV E | 4537.570 | 2 | 10 | I A |
| 4456.708 | 3d | 40 | I A | 4537.952 | 200 | 15 | IV E |
| 4457.79 | 2 | 1 | IV E | 4538.53 | 12 | 2 | IV E |
| 4458.517 | 400 | 30 | III E | 4539.840 | 1— | 5 | II A |
| 4459.290 | 80 | 60 | I | 4540.188 | 30 | 6 | IV E |
| 4463.897 | 3 | 15 | II A | 4542.057 | 60 | 12 | III E |
| 4467.342 | 500 | 20 | III E | 4543.948 | 250 | 20 | III E |
| 4469.658 | 10 | 2 | IV E | 4544.826 | 15 | 3 | IV E |
| 4470.475 | 1 | 4 | II A | 4545.810 | 3 | 1— | IV E |
| 4470.886 | 100 | 100r | I | 4550.032 | 8 | 20 | I A |
| 4471.504 | 1 | 8 | II A | 4552.659 | 150 | 12 | III E |
| 4472.156 | 2d | ..... | V E | 4554.449 | 100d | 15 | IV E |
| 4472.426 | 80 | 10 | III E | 4556.535 | 8d | 1 | IV E |
| 4473.015 | 150 | 15 | III E | 4556.626 | 4d | 40 | I A |
| 4475.176 | 8 | 4 | IV E | 4560.430 | 50 | 10 | III E |
| 4477.505 | 6 | 15 | I A | 4561.188 | 2 | 1— | IV E |
| 4478.657 | 125 | 10 | IV E | 4564.101 | 12 | 4 | IV E |
| 4480.316 | 30 | 60 | I A | 4566.206 | 200 | 15 | III E |
| 4483.647 | 1— | 5 | III A | 4566.767 | 12 | 25 | I A |

TABLE I—*Continued*

| λ | Intensity | | Class | λ | Intensity | | Class |
|---|---|---|---|---|---|---|---|
| | Arc | Furnace | | | Arc | Furnace | |
| 4569.579 | 6 | 20 | I A | 4640.14 | 4d | ..... | V E |
| 4577.690 | 250 | 15 | III E | 4640.518 | 3 | 8 | I A |
| 4578.014 | 5 | 1 | IV E | 4641.524 | 2d | ..... | V E |
| 4578.719 | 5 | 1 | IV E | 4642.235 | 500 | 20 | IV E |
| 4579.091 | 4 | 1— | IV E | 4643.59 | 1 | 1 | III |
| 4580.188 | 1 | 12 | II A | 4645.1 | 1d | 1 | IV |
| 4581.581 | 100 | 100r | I | 4645.405 | 100 | 100r | I |
| 4581.729 | 150 | 80 | I | 4646.684 | 200 | 8 | IV E |
| 4584.831 | 150 | 15 | IV E | 4646.90 | 1d | 2 | III A |
| 4589.431 | 2 | ..... | V E | 4647.53 | 50 | 3 | IV E |
| 4591.818 | 100 | 10 | IV E | 4648.078 | 40 | 40 | I |
| 4593.394 | 3d | ..... | V E | 4648.160 | 100 | 4 | IV E |
| 4593.544 | 150 | 12 | IV E | 4648.629 | 2 | ..... | V E |
| 4594.587 | 3d | ..... | V E | 4649.158 | 2 | ..... | V E |
| 4595.291 | 250 | 15 | IV E | 4649.491 | 100 | 80r | I |
| 4596.743 | 60 | 100r | I | 4652.670 | 6 | 1 | IV E |
| 4598.285 | 4 | 8 | I A | 4654.31 | 2d | ..... | V |
| 4598.354 | 10 | 2 | IV E | 4654.62 | 1 | ..... | V E |
| 4602.024 | 1 | 10 | I A | 4655.129 | 50 | 4 | IV E |
| 4603.12 | 3d | 1— | IV E | 4655.35 | 1d | ..... | V E |
| 4603.98 | 1d | ..... | V E | 4656.94 | 1 | ..... | V E |
| 4604.180 | 80d | 12 | IV E | 4657.20 | 1 | ..... | V E |
| 4606.514 | 100 | 15 | III E | 4659.08 | 2 | ..... | V E |
| 4606.877 | 10 | 1 | IV E | 4660.45 | 2 | 1 | IV |
| 4611.248 | 20 | 50 | I A | 4663.556 | 100 | 80r | I |
| 4611.670 | 2d | 2 | IV | 4664.509 | 2 | 10 | II A |
| 4612.075 | 1 | ..... | V E | 4665.131 | 20 | 2 | IV E |
| 4613.505 | 12 | 1 | IV E | 4666.27 | 2 | ..... | V E |
| 4615.441 | 150 | 8 | IV E | 4667.52 | 2d | ..... | V E |
| 4615.690 | 300 | 20 | III E | 4669.396 | 500 | 20 | III E |
| 4616.489 | 10 | 3 | IV E | 4669.650 | 500 | 20 | III E |
| 4616.615 | 1 | 12 | II A | 4670.747* | 50 | 60 | I |
| 4618.228 | 2 | 10 | II A | 4670.834 | 60 | 80 | I |
| 4618.77 | 1d | ..... | V E | 4671.45 | 2 | ..... | V E |
| 4620.25 | 1 | ..... | V E | 4671.855 | 5 | ..... | V E |
| 4620.77 | 1d | ..... | V E | 4673.239 | 2 | ..... | V E |
| 4621.21 | 1d | ..... | V E | 4673.80 | 1 | 1 | IV |
| 4624.14 | 2d | 2 | III | 4674.599 | 600 | 25 | III E |
| 4624.972 | 4d | ..... | IV E | 4676.911 | 500 | 20 | III E |
| 4628.77 | 2d | ..... | V E | 4677.71 | 1 | 1 | IV |
| 4629.430 | 5 | 20 | I A | 4678.114 | 3 | 4 | I |
| 4630.206 | 60 | 8 | IV E | 4680.03 | 1 | 5 | IV A |
| 4630.59 | 2d | ..... | V E | 4681.551 | 50 | 40 | II |
| 4630.97 | 2d | 2 | III | 4682.689* | 50 | ? | IV E |
| 4632.770 | 1d | 8 | I A | 4683.23 | 2d | ..... | V E |
| 4633.171 | 4 | 1— | IV E | 4684.03 | 1d | ..... | V E |
| 4635.17 | 1d | ..... | V E | 4684.196 | 1 | 4 | II A |
| 4636.265 | 25 | 1— | V E | 4687.183 | 400 | 6 | IV E |
| 4636.75 | 2d | 2 | III | 4688.11* | 1 | ..... | V E |
| 4638.63 | 1 | 1— | IV | 4688.733 | 150 | 100 | I |
| 4639.12 | 2 | 1 | IV | 4689.573 | 50 | ..... | V E |

TABLE I—*Continued*

| λ | Intensity | | Class | λ | Intensity | | Class |
|---|---|---|---|---|---|---|---|
| | Arc | Furnace | | | Arc | Furnace | |
| 4691.89* | 3d | ..... | V E | 4747.56 | 3d | ..... | V |
| 4693.13 | 1 | ..... | V E | 4747.9 | 1 | 1 | IV |
| 4693.628 | 150 | 2? | IV E | 4748.81 | 4d | ..... | V E |
| 4696.422 | 2 | ..... | V E | 4749.6 | 2 | ..... | V E |
| 4699.339 | 80 | 1 | IV E | 4750.725 | 60 | 50 | II |
| 4699.68 | 1 | 4 | IV A | 4752.3 | 2 | ..... | V E |
| 4701.26 | 3 | ..... | V E | 4752.9 | 3d | ..... | V E |
| 4703.31 | 1d | ..... | V E | 4753.7 | 2 | 3 | IV |
| 4704.397 | 500 | 8 | IV E | 4755.374 | 30 | 2 | IV E |
| 4704.993 | 2 | ..... | V E | 4757.09 | 4d | ..... | V E |
| 4706.21 | 1d | ..... | V E | 4757.50 | 2 | 2 | IV |
| 4706.54 | 2 | ..... | V E | 4758.34 | 2 | ..... | V E |
| 4707.53 | 1 | ..... | V E | 4758.82 | 4 | ..... | V E |
| 4710.643 | 50 | ..... | V E | 4760.033 | 50 | 60 | II |
| 4710.80 | 1d | 1— | IV | 4760.27 | 300 | 150r | I |
| 4713.057 | 150 | ? | IV E | 4760.725 | 10 | ..... | V E |
| 4714.623 | 60 | ..... | V E | 4761.58 | 5 | ..... | V E |
| 4715.265 | 150 | ..... | V E | 4763.43 | 4d | 1 | IV |
| 4716.097 | 250 | 80 | I | 4766.158 | 10 | ..... | V E |
| 4716.69 | 3 | ..... | V E | 4767.0 | 2d | 2 | IV |
| 4717.071 | 150 | 125 | I | 4768.37 | 3 | 2 | IV |
| 4717.4 | 2d | ..... | V E | 4770.20* / 4770.29* | 30 | 20 / 4 | I |
| 4717.718 | 150 | 3 | IV E | 4771.687 | 3d | ..... | V E |
| 4718.329 | 150 | 4 | IV E | 4772.46 | 2 | 2 | IV |
| 4718.641 | 40 | 30 | I | 4772.98 | 2 | 2 | IV |
| 4719.838 | 200 | 6 | IV E | 4774.147 | 80 | 2 | IV E |
| 4720.120 | 30 | ..... | V E | 4775.53 | 4d | ..... | V E |
| 4721.393 | 20 | ..... | V E | 4775.9 | 1 | 1 | IV |
| 4721.66 | 3d | 2 | IV | 4777.3 | 1d | 1 | IV |
| 4722.614 | 3d | 4? | IV | 4777.62 | 2 | 2 | IV |
| 4722.93 | 3d | ..... | V E | 4777.846 | 200 | 6 | IV E |
| 4723.67 | 4d | ..... | V E | 4778.63* | 4d | 1 | IV |
| 4726.021 | 100 | 4 | IV E | 4779.225 | 6 | ..... | V E |
| 4726.48 | 1d | ..... | V E | 4781.55 | 6d | ..... | V E |
| 4727.11 | 1 | ..... | V | 4781.840 | 60 | 2 | IV E |
| 4728.423 | 300 | 100 | I | 4783.103 | 300 | 200 | I |
| 4729.77 | 1 | ..... | V | 4785.864 | 150 | 125 | I |
| 4730.95 | 1 | ..... | V E | 4786.21 | 4d | ..... | V E |
| 4731.34 | 2d | ..... | V E | 4789.958 | 50 | 50 | II |
| 4731.57 | 1 | ..... | V | 4791.584 | 200 | 4 | IV E |
| 4732.42 | 1 | ..... | V E | 4794.3 | 3d | ..... | V E |
| 4733.88 | 2 | ? | IV ? | 4795.00 | 2 | 1 | IV |
| 4736.11 | 2d | ? | IV ? | 4795.880 | 2 | 1 | IV |
| 4736.50 | 2d | ..... | V E | 4798.89 | 8d | ..... | V E |
| 4736.7 | 2 | ..... | V E | 4801.83 | 2d | 1 | IV |
| 4736.96 | 3 | ? | IV ? | 4802.27 | 3 | 1 | IV |
| 4739.555 | 4 | ..... | V E | 4802.98 | 6d | ..... | V E |
| 4741.723 | 40 | 1 | IV E | 4803.409 | 5 | 3 | IV |
| 4742.21 | 3 | 2 | IV | 4804.903 | 6d | ..... | IV E |
| 4742.48 | 4 | ..... | V E | 4805.09 | 2d | 2 | IV |
| 4745.680 | 500 | 12 | IV E | | | | |

TABLE I—*Continued*

| λ | Intensity | | Class | λ | Intensity | | Class |
|---|---|---|---|---|---|---|---|
| | Arc | Furnace | | | Arc | Furnace | |
| 4807.37 | 2d | 2 | IV | 4873.194 | 6d | ..... | V E |
| 4808.45 | 2 | ..... | V E | 4873.84 | 1 | ..... | V |
| 4808.99 | 3 | 3 | IV | 4874.37 | 2d | 2 | IV |
| 4812.61 | 3 | ..... | V E | 4875.61 | 2d | ..... | V E |
| 4813.21 | 3 | 2 | IV | 4875.89 | 1 | 1 | IV |
| 4814.1 | 1 | 2 | IV A | 4877.62 | 8 | ..... | V E |
| 4814.3 | 2d | 1 | IV | 4878.97 | 1 | 1— | IV |
| 4815.808 | 400 | 8 | III E | 4879.31 | 5 | ..... | V E |
| 4816.012 | 100 | 1 | IV E | 4879.70 | 3d | 1 | IV |
| 4816.48 | 4d | ..... | V E | 4883.772 | 100 | 100 | II |
| 4820.76 | 2d | ..... | V E | 4883.971 | 200 | 100 | II |
| 4822.85 | 2 | 1 | IV | 4886.05 | 5 | 2 | IV |
| 4824.67 | 4d | ..... | V E | 4886.62 | 4 | 2 | IV |
| 4825.38 | 4d | ..... | V E | 4886.97 | 8 | 3 | IV |
| 4826.57 | 4d | ..... | V E | 4889.28 | 2 | 3 | III |
| 4827.80 | 5 | 2 | IV | 4890.33 | 6 | 2 | IV |
| 4828.74 | 3d | 1 | IV | 4890.76 | 3 | 2 | IV |
| 4829.568 | 250 | 3 | IV E | 4891.46 | 2 | 1 | IV |
| 4830.68 | 4 | ..... | V E | 4891.94 | 6d | ..... | V E |
| 4832.33 | 3 | 1 | IV | 4893.35 | 100d | ..... | V E |
| 4833.324 | 20 | ..... | V E | 4893.77 | 6 | 2 | IV |
| 4834.618 | 100 | 1 | IV E | 4894.305 | 25 | 1 | IV E |
| 4835.72 | 2 | 2 | IV | 4895.38 | 1 | 1 | IV |
| 4836.669 | 20 | 1? | IV E | 4897.83 | 5 | 1 | IV |
| 4837.646 | 20 | ..... | V E | 4899.88 | 1d | 2 | IV A |
| 4838.64 | 2 | ..... | V E | 4900.733 | 20d | ..... | V E |
| 4841.701 | 400 | 150 | I | 4901.02 | 4d | ..... | V E |
| 4844.208 | 300 | 6 | IV E | 4901.897 | 8d | {3 | IV |
| 4844.53 | 2 | 1 | IV | | | {.... | V E |
| 4845.35 | 2 | 1 | IV | 4904.968 | 80 | 80 | II |
| 4847.05 | 2d | ..... | V E | 4905.79 | 5 | 2 | IV |
| 4847.760 | 200 | 2 | IV E | 4907.79 | 2 | 2 | IV |
| 4848.318 | 100 | 100 | I | 4910.400 | 150 | 100 | II |
| 4851.53 | 2 | ..... | V E | 4913.248 | 150 | 1 | IV E |
| 4853.65 | 1 | 2 | IV A | 4914.297 | 8 | ..... | V E |
| 4854.365 | 150 | 3 | IV E | 4916.96 | 1 | 1 | IV |
| 4856.56 | 4 | 1? | IV | 4917.41 | 3d | ..... | V E |
| 4857.14 | 2 | 1— | IV | 4918.986 | 125 | 100 | I |
| 4857.58 | 1 | 1 | IV | 4919.90 | 2 | 1 | IV |
| 4859.551 | 100 | 2 | IV E | 4920.38 | 30d | ..... | V E |
| 4859.84 | 5d | ..... | V E | 4921.56 | 2 | 1 | IV |
| 4860.69 | 3 | 1 | IV | 4922.47 | 5 | ..... | V E |
| 4861.04 | 2 | ..... | V E | 4922.74 | 3 | 2 | IV |
| 4861.64 | 1 | 1 | IV | 4923.827 | 15 | ..... | V E |
| 4862.1 | 2 | ..... | V E | 4924.044 | 30 | 30 | II |
| 4864.22 | 5d | ..... | V E | 4929.563 | 10 | ..... | V E |
| 4865.39 | 4 | ..... | V E | 4930.93 | 1 | ..... | V E |
| 4866.59 | 3 | 1 | IV | 4933.30 | 4 | ..... | V E |
| 4868.14 | 3 | ..... | V | 4935.47 | 2 | ..... | V E |
| 4869.98 | 40d | ..... | V E | 4936.031 | 20 | ..... | V E |
| 4871.30 | 1 | 2 | IV A | 4936.580 | 10 | 2 | IV |

TABLE I—*Continued*

| λ | Intensity | | Class | λ | Intensity | | Class |
|---|---|---|---|---|---|---|---|
| | Arc | Furnace | | | Arc | Furnace | |
| 4938.100 | 100 | 1 | IV E | 5016.61 | 20d | ..... | V E |
| 4940.61 | 6d | ..... | V E | 5017.55 | 5 | 1 | IV |
| 4941.3 | 2 | ..... | V E | 5019.14 | 3 | 2 | IV |
| 4943.40 | 2 | 2 | IV | 5022.46 | 2 | 1 | IV |
| 4945.1 | 3d | ..... | V E | 5023.501 | 20 | ..... | V E |
| 4946.04 | 2 | 2 | IV | 5026.20 | 2d | ..... | V E |
| 4946.321 | 40 | 60 | II | 5028.44 | 80d | ..... | V E |
| 4947.43 | 2 | 1 | IV | 5029.60 | 4 | 1 | IV |
| 4948.05 | 3d | ..... | V E | 5029.83 | 2 | ..... | V |
| 4948.627 | 150 | 2 | IV E | 5030.98 | 4 | ..... | V |
| 4951.30 | 3 | 1 | III | 5031.18 | 6d | ..... | V E |
| 4952.371 | 150 | 1 | IV E | 5032.57 | 2 | 1 | IV |
| 4952.81 | 2 | 1 | IV | 5036.215 | 6 | ..... | V E |
| 4953.032 | 20 | ..... | V E | 5039.10 | 4 | 2 | IV |
| 4955.95 | 2d | ..... | V E | 5039.45 | 4 | 1 | IV |
| 4956.13 | 4d | ..... | V E | 5039.73 | 2 | 1 | IV |
| 4956.44 | 2 | 1 | IV | 5039.95 | 2d | ..... | V E |
| 4956.70 | 3d | 2 | IV | 5041.93 | 4 | 2 | IV |
| 4957.67 | 2 | ..... | V E | 5043.41 | 2 | 1 | IV |
| 4958.43 | 3 | 2 | IV | 5044.279 | 80 | 40 | I |
| 4960.04 | 6d | ..... | V E | 5049.509 | 10 | 30 | I A |
| 4961.25 | 3 | 2 | IV | 5052.760 | 150d | 3 | IV E |
| 4961.936 | 250 | 3 | IV E | 5054.07 | 4 | 1 | IV |
| 4964.22 | 3 | 2 | IV | 5054.50 | 2 | 1 | IV |
| 4964.560 | 20 | 1 | IV E | 5057.742 | 25d | ..... | V E |
| 4967.02 | 2 | 1 | IV | 5058.86 | 3 | ..... | V E |
| 4967.73 | 4 | 2 | IV | 5059.846 | 40 | ? | IV ? |
| 4968.17 | 2 | 1 | IV | 5060.927 | 15 | 30 | II A |
| 4970.08 | 2d | ..... | V E | 5061.37 | 2 | 1 | IV |
| 4972.16 | 25d | ..... | V E | 5064.238 | 8 | ..... | V E |
| 4973.735 | 12 | ..... | V E | 5066.390 | 6 | ..... | V E |
| 4974.75 | 5 | 1 | IV | 5066.86 | 2d | ..... | V E |
| 4975.975 | 60 | 60 | I | 5069.460 | 150d | ..... | V E |
| 4981.47 | 2d | 1 | IV | 5069.88 | 3 | ..... | V |
| 4981.73 | 10d | ..... | V E | 5071.200 | 100 | 60 | I |
| 4983.38 | 5d | ..... | V E | 5071.80 | 2 | ..... | V |
| 4984.84 | 1 | 1 | IV | 5072.46 | 5 | 2 | IV |
| 4985.89 | 2d | ..... | V E | 5076.69 | 15 | ? | IV? |
| 4986.81 | 8 | 3 | III | 5077.60 | 3 | 3 | IV |
| 4989.44 | 10 | ..... | V E | 5078.00 | 3d | ..... | V E |
| 4992.02 | 20d | ..... | V E | 5079.858 | 30 | 3 | III |
| 4994.97 | 5 | 3 | III | 5083.30 | 5d | ..... | V E |
| 5000.04 | 3d | ..... | V E | 5086.11 | 2 | ..... | V |
| 5001.220 | 15 | ..... | V E | 5087.079 | 8 | ..... | V E |
| 5002.18 | 2 | 1 | IV | 5087.65 | 4d | ..... | V E |
| 5003.37 | 3 | 1 | IV | 5088.319 | 20 | 30 | I |
| 5008.39 | 3 | 1 | IV | 5088.97 | 3d | ..... | V E |
| 5009.16 | 1 | 1 | IV | 5089.74 | 3d | ..... | V E |
| 5009.33 | 3 | ..... | V | 5090.02 | 3d | ..... | V E |
| 5010.16 | 2 | ..... | V E | 5091.16 | 2 | 1? | IV ? |
| 5010.89 | 3 | 10 | I A | 5091.81 | 4 | 2? | IV ? |

TABLE I—*Continued*

| λ | Intensity | | Class | λ | Intensity | | Class |
|---|---|---|---|---|---|---|---|
| | Arc | Furnace | | | Arc | Furnace | |
| 5098.44 | 3 | ..... | V | 5161.17 | 4 | ? | IV ? |
| 5100.215 | 15 | ..... | V E | 5164.62 | 5 | ? | IV ? |
| 5100.31 | 10 | ..... | V E | 5166.06 | {10 6} | ..... | V E |
| 5100.39 | 15 | 2 | III | 5167.28 | 4 | 3 | IV |
| 5101.82 | 1 | 1 | IV | 5168.348 | 20 | 5 | IV |
| 5102.21 | 2 | 1 | IV | 5169.570 | 8d | ..... | V E |
| 5102.36 | 1d | ? | IV ? | 5172.738 | 80 | 40 | I |
| 5103.093 | 200d | 1 | IV E | 5173.64 | 4 | 1 | IV |
| 5104.06 | 10d | ..... | V E | 5175.419 | 150 | 80 | I |
| 5104.479 | 100d | ..... | V E | 5176.23 | 3 | 2 | IV |
| 5106.68 | 4 | —? | V | 5178.01 | {10 6} | ..... | V E |
| 5107.01 | 4 | 1 | IV | 5179.22 | 3 | 2 | IV |
| 5108.96 | 2 | ..... | V | 5181.45 | 2 | 1 | IV |
| 5110.54 | 3 | ..... | V | 5183.14 | 2 | 2 | IV |
| 5111.168 | 3 | ..... | V | 5183.67 | 2 | ..... | V E |
| 5111.91 | 4d | ..... | V E | 5185.528 | 2 | 6 | I A |
| 5112.304 | 30d | ..... | V E | 5186.84 | 1 | 1 | IV |
| 5113.32 | 3 | 1 | IV | 5187.093 | 10 | 15 | I |
| 5115.376 | 8 | 2 | IV | 5187.21 | 4 | 1 | IV |
| 5116.700 | 100d | ..... | V E | 5194.729 | 20 | 4 | III |
| 5117.162 | 100 | 80 | I | 5200.592 | 200 | 100 | I |
| 5118.40 | 2 | 1 | IV | 5201.454 | 30 | 6 | III |
| 5122.136 | 125 | 60 | I | 5202.36 | 4 | 1 | IV |
| 5123.71 | 2 | ..... | V | 5202.73 | 20d | 3 | IV |
| 5124.86 | 8d | ..... | V E | 5203.68 | 5 | 2 | IV |
| 5125.52 | {2 1} | ..... | V E ? | 5206.71 | 3 | 1 | IV |
| 5127.18 | 4d | ? | V E ? | 5207.15 | 4d | ..... | V E |
| 5130.28 | 4 | ? | IV ? | 5207.63 | 4 | 1 | IV |
| 5132.21 | 15 | 1 | III | 5209.27 | 1 | 1 | IV |
| 5135.86 | 10 | 1 | IV | 5209.924 | 40 | 4 | III |
| 5137.43 | 3 | 1 | IV | 5210.750 | 10 | 10 | I |
| 5138.72 | 1 | 1— | IV | 5211.736 | 8 | 3 | IV |
| 5140.43 | 2 | ? | IV ? | 5212.192 | 8 | 3 | IV |
| 5143.298 | 20 | 2? | III | 5215.61 | 5 | 3 | IV |
| 5144.96 | 5 | ? | III | 5216.44 | 5d | 4 | IV |
| 5145.16 | 3 | 1 | IV | 5218.398 | 50 | 8 | III |
| 5145.819 | 10d | 12 | I | 5221.116 | 40 | 4 | III |
| 5148.06 | 2 | 1— | IV | 5221.308 | 30 | 6 | III |
| 5150.45 | 3 | ..... | V | 5222.48 | 3 | 2 | IV |
| 5151.95 | 4 | ? | IV ? | 5224.69 | 8d | 3 | IV |
| 5152.60 | 4d | ..... | V | 5225.26 | 2d | 1 | IV |
| 5154.230 | {10 10 | ..... | V E | 5225.70 | 2 | 3 | IV |
| 5155.031 | 125d | ..... | V E | 5228.80 | 10 | 1 | IV |
| 5155.863 | 20 | 4 | III | 5228.90 | 3 | ..... | V E |
| 5157.07 | 3d | ..... | V E | 5229.59 | 4 | 2 | IV |
| 5157.228 | 20 | 30 | I | 5229.87 | 3 | 2 | IV |
| 5157.57 | 4 | ? | IV ? | 5231.13 | 2 | 1 | IV |
| 5157.89 | 4 | 1 | IV | 5232.39 | 2 | 1 | IV |
| 5159.521 | 5 | ..... | V E | 5234.175 | 10d | ..... | V E |

TABLE I—*Continued*

| λ | Intensity | | Class | λ | Intensity | | Class |
|---|---|---|---|---|---|---|---|
| | Arc | Furnace | | | Arc | Furnace | |
| 5237.577 | 6 | 2 | IV | 5318.053 | 6 | 3 | IV |
| 5238.104 | 8 | 5 | IV | 5318.96 | 2 | 1 | IV |
| 5238.51 | 1 | 2 | IV A | 5320.598 | 100d | 100 | I |
| 5243.74 | 3d | 2 | IV | 5320.73 | 4 | 1 | IV |
| 5244.49 | 1 | 2 | IV A | 5321.27 | 5 | 2 | IV |
| 5245.60 | 5 | 3 | IV | 5321.82 | 5d | 1 | IV |
| 5246.00 | 2 | 1 | IV | 5323.53 | 2d | ..... | V E |
| 5248.40 | 3d | 2 | IV | 5324.99 | 4 | 2 | IV |
| 5251.915 | 150d | 100 | I | 5326.56 | 6 | 3 | IV |
| 5252.77 | 8d | ..... | V E | 5326.89 | 4 | 2 | IV |
| 5253.44 | 4 | 2 | IV | 5327.24 | 2 | 1 | IV |
| 5253.797 | 12 | 4 | IV | 5327.44 | 2 | 1 | IV |
| 5256.77 | 1 | 1 | IV | 5328.47 | 1 | 1 | IV |
| 5257.11 | 4 | 3 | IV | 5332.09 | 10 | 5 | IV |
| 5259.10 | 4 | 2 | IV | 5333.33 | 4 | 3 | IV |
| 5260.54 | 3 | 2 | IV | 5334.77 | 2d | ..... | V E ? |
| 5263.02 | 1 | 1 | IV | 5340.31 | 4 | 2 | IV |
| 5263.27 | 3 | 2 | IV | 5341.286 | 100 | 50 | I |
| 5264.41 | 3 | 2 | IV | 5342.76 | 4 | 3 | IV |
| 5265.670 | 20 | 25 | I | 5348.080 | 10 | 30 | I A |
| 5269.97 | 5 | 10 | I A | 5348.744 | 10d | 5 | III |
| 5271.403 | 200 | 125 | I | 5349.142 | 15 | 40 | I A |
| 5272.818 | 12d | ..... | V E | 5350.616 | 15 | 20 | II |
| 5274.13 | 4d | ..... | V E | 5351.33 | 1 | 2 | IV A |
| 5280.510 | 3 | 2 | IV | 5352.29 | 4 | 3 | IV |
| 5282.906 | 100 | 50 | I | 5353.725 | 1 | 5 | II A |
| 5284.33 | 2 | 1 | IV | 5355.883 | 15 | 4 | IV |
| 5285.187 | 8 | 3 | IV | 5359.3* | 4d | 4? | IV |
| 5285.87 | 1 | 1 | IV | 5360.76 | 4 | 2 | IV |
| 5286.36 | 2d | 2 | IV | 5364.39 | 15d | ..... | V E |
| 5287.66 | 1 | 1 | IV | 5366.56 | 5 | 2 | IV |
| 5288.14 | 3 | 2 | IV | 5368.365 | 150 | 80 | I |
| 5289.94 | 15d | 4 | IV | 5369.18 | 10d | ..... | V E |
| 5291.19 | 3 | 2 | IV | 5370.055 | 20 | 5 | III |
| 5294.651 | 10 | 5 | IV | 5372.92 | 3 | 2 | IV |
| 5295.51 | 2 | 2 | IV | 5373.99 | 5 | 3 | IV |
| 5296.94 | 2d | ..... | V E | 5374.28 | 4 | 6 | III |
| 5299.216 | 4 | 15 | I A | 5375.11 | 1 | 2 | IV A |
| 5301.66 | 2 | 2 | IV | 5375.40 | 8 | 5 | III |
| 5302.70 | 5 | 3 | IV | 5378.09 | 15d | 20 | III |
| 5302.930 | 12 | ..... | V E | 5378.71 | 2 | 1 | IV |
| 5303.23 | 4 | 2 | IV | 5380.40 | 8 | 8 | III |
| 5304.27 | 2 | 1 | IV | 5380.76 | 3 | 2 | IV |
| 5304.54 | 5d | 2 | IV | 5381.00 | 5 | 3 | IV |
| 5308.81 | 2 | 2 | IV | 5382.05 | 5 | 3 | IV |
| 5309.499 | 10 | 5 | IV | 5382.26 | 1 | 1 | IV |
| 5310.21 | 3 | 1 | IV | 5382.60 | 3 | 2 | IV |
| 5311.85 | 2 | 1 | IV | 5383.54 | 2 | 4 | IV A |
| 5312.23 | 12d | ..... | V E | 5383.89 | 5 | 2 | IV |
| 5312.84 | 2 | 1 | IV | 5384.89 | 10 | 5 | III |
| 5313.757 | 10 | 3 | IV | 5385.03 | 2? | 1 | IV |

TABLE I—*Continued*

| λ | Intensity | | Class | λ | Intensity | | Class |
|---|---|---|---|---|---|---|---|
| | Arc | Furnace | | | Arc | Furnace | |
| 5385.28 | 1 | 1 | IV | 5433.55 | 10 | 6 | III |
| 5385.97 | 4 | 6 | III | 5433.82 | 30 | 20 | II |
| 5386.45 | 2 | 1 | IV | 5436.33 | 40 | 5 | III |
| 5386.70 | 6 | 2 | IV | 5436.66 | 3d | 2 | IV |
| 5387.89* | 15? | 6 | III | 5438.97 | 2 | 1 | IV |
| 5388.03* | 6? | 4 | III | 5439.85 | 2 | 1 | IV |
| 5388.52 | 3 | 2 | IV | 5440.66 | 5 | 3 | IV |
| 5389.85 | 15 | 5 | III | 5440.89 | 3 | 2 | IV |
| 5391.62 | 8 | 2 | III | 5441.93 | 4 | 2 | IV |
| 5392.69 | 30 | 6 | III | 5442.06 | 1 | 1 | IV |
| 5393.55 | 5 | 3 | III | 5442.56 | 1 | 1 | IV |
| 5393.94 | 2 | 1 | IV | 5442.95 | 5 | 3 | III |
| 5394.48 | 10d | 1 | IV E | 5444.98 | 2 | 2 | IV |
| 5395.48 | 1 | 1 | IV | 5445.91 | 2 | 1 | IV |
| 5397.03 | 2 | 2 | IV | 5446.84 | 2 | 1 | IV |
| 5397.18 | 1 | 1 | IV | 5447.66 | 3 | 3 | IV |
| 5397.92 | 10 | 4 | III | 5448.04 | 1 | ..... | V E |
| 5398.17 | 3 | ..... | V E | 5448.26 | 2 | ..... | V E |
| 5398.97 | 4 | ..... | V E | 5448.94 | 2 | 2 | IV |
| 5399.69 | 3 | 1 | IV | 5449.58 | 8 | 5 | III |
| 5400.85 | 10 | 4 | III | 5450.05 | 20d | 20 | III |
| 5401.42 | 4 | 1 | IV | 5450.52 | 2 | 2 | IV |
| 5402.05 | 5d | 20 | II A | 5451.02 | 1 | 1 | IV |
| 5402.32 | 12 | 5 | III | 5452.25 | 4 | 3 | IV |
| 5403.70 | 200d | 80 | I | 5453.00 | 300 | 150r | II |
| 5404.98 | 15 | 5 | III | 5453.96 | 2 | 1 | IV |
| 5405.23 | 200 | 125r | II | 5455.62 | 1 | 1 | IV |
| 5406.64 | 2 | 1 | IV | 5455.88 | 1 | 1 | IV |
| 5406.81 | 10 | 5 | III | 5459.60 | 4 | 3 | III |
| 5407.86 | 2 | ..... | V E | 5460.61 | 2 | 1 | IV |
| 5408.84 | 3 | 2 | III | 5460.90 | 3d | 2 | IV |
| 5411.15 | 10 | 40 | II A | 5461.55 | 30 | 6 | III |
| 5411.39 | 100 | 50 | II | 5462.34 | 8 | 5 | III |
| 5412.80 | 10 | 4 | III | 5463.18 | 4 | 2 | IV |
| 5415.78 | 2 | 4 | II A | 5463.80 | 3d | 5 | III |
| 5415.98 | 20 | 4 | IV E | 5466.27 | 2 | 2 | IV |
| 5416.36 | 8 | 3 | III | 5466.72 | 250 | 125r | II |
| 5419.07 | 15 | 8 | III | 5467.21 | 4 | ..... | V E |
| 5419.47* | 15d | 8 | III | 5468.02 | 4 | 4 | III |
| 5420.51* | 2 | 1 | IV | 5469.25 | 3 | 2 | IV |
| 5421.34 | 2 | 2 | IV | 5470.29* | 6 | 6 | III |
| 5421.57 | 80 | 30 | I | 5470.85 | 1 | 1 | IV |
| 5423.98 | 2 | 1 | IV | 5471.26 | 2 | 3 | IV |
| 5425.63 | 20 | 3 | III | 5471.50 | 2 | 3 | IV |
| 5425.94 | 2 | 1 | IV | 5472.03 | 4 | 3 | IV |
| 5426.39 | 4 | 2 | IV | 5472.33 | 2 | 3 | IV |
| 5427.61* | 6 | 4 | III | 5472.68 | 8d | 8 | III |
| 5430.62 | 10 | 4 | III | 5473.71 | 10 | 6 | III |
| 5430.90 | 2 | 2 | IV | 5473.91 | 10 | 5 | III |
| 5431.32 | 2 | 1 | IV | 5475.29 | 8 | 5 | III |
| 5431.80 | 6 | 4 | III | 5476.88 | 1 | 1 | IV |

TABLE I—*Continued*

| λ | Intensity | | Class | λ | Intensity | | Class |
|---|---|---|---|---|---|---|---|
| | Arc | Furnace | | | Arc | Furnace | |
| 5478.29 | 10 | ..... | V E | 5523.30 | 3 | 1 | IV |
| 5478.59 | 2 | 2 | IV | 5523.55 | 2 | 2 | IV |
| 5479.75 | 3 | 2 | III | 5523.94 | 2 | 2 | IV |
| 5480.67 | 8 | 4 | III | 5525.61 | 20 | 5 | III |
| 5482.17 | 4 | 3 | III | 5526.15 | 4 | 3 | IV |
| 5484.28 | 2 | 1 | IV | 5526.32 | 3 | 2 | IV |
| 5484.59 | 10 | 6 | III | 5528.55 | 1 | 2 | IV A |
| 5485.42 | 150 | 100r | II | 5528.95 | 3 | 3 | IV |
| 5485.71 | 2? | 3 | IV | | 4 | 3 | IV |
| 5488.07 | 3 | 2 | IV | 5529.99 | 10 | 8 | III |
| 5488.25 | 5 | 4 | III | 5531.02 | 4 | 4 | IV |
| 5488.93* | 2 | 1 | IV | 5532.63 | 8 | 6 | IV |
| 5489.40 | 3 | 4 | III | 5532.86 | 4 | 4 | IV |
| 5490.08 | 3 | 1 | IV | 5534.20 | 1 | 1 | IV |
| 5490.65 | 6 | ..... | V E | 5536.19 | 3 | 4 | IV |
| 5491.31 | 2 | 1 | IV | 5537.07 | 30 | ..... | V E |
| 5492.50* | 5 | 3 | IV | 5537.18* | 3? | 6 | IV A |
| 5493.72 | 300d? | 200r | II | 5538.39 | 10 | 3 | IV |
| 5494.33 | 30 | 20 | III | 5539.20 | 2 | 1 | IV |
| 5494.88 | 1 | 1 | IV | 5542.37 | 3 | 1 | IV |
| 5495.62 | 4 | 5 | III | 5542.74 | 5 | 3 | IV |
| 5496.84 | 4 | 3 | IV | 5542.89 | 3 | 3 | IV |
| 5497.14 | 1 | 5 | III A | 5543.61 | 6 | 5 | III |
| 5498.21 | 200 | 150r | II | 5544.50 | 8d | 6 | IV |
| 5498.49* | ? | 4 | IV | 5545.11 | 1 | 1 | IV |
| 5500.90 | 10 | 25 | II A | 5548.33 | 1 | 1 | IV |
| 5501.75 | 8d? | 20 | II A | 5548.95 | 150 | 125 | I |
| 5502.84 | 2 | 3 | IV | 5550.11* | ? | 4 | IV |
| 5503.52 | 2d | 2 | IV | 5550.40 | 300 | 200r | II |
| 5504.05 | 4 | 4 | IV | 5551.45 | 10 | 4 | III |
| 5505.20 | 5 | 3 | IV | 5553.03 | 10 | 2 | IV |
| 5507.17 | 3d | 2 | IV | 5554.44 | 5d | 4 | IV |
| 5509.35* | 2d | 2 | IV | 5554.75 | 1 | ..... | V E |
| 5509.70 | 3 | 1 | IV E | 5555.13 | 1 | 2 | IV A |
| 5510.11 | 3 | 1 | IV | 5555.49 | 2 | 3 | IV |
| 5510.42 | 4 | 1 | IV | 5558.20 | 1 | 1 | IV |
| 5510.80 | 4 | 3 | IV | 5558.62 | 2 | 1 | IV |
| 5511.09 | 60 | 40 | I | 5560.64 | 3 | 4 | IV |
| 5511.38 | 5 | 3 | IV | 5561.17 | 4 | 3 | IV |
| 5512.10 | 200 | 100 | I | 5561.37 | 50 | 20 | II |
| 5512.96 | 5 | 3 | IV | 5561.82 | 1 | 1 | IV |
| 5513.21 | 2 | 2 | IV | 5562.85 | 4 | 3 | III |
| 5513.93 | 3 | 2 | IV | 5563.18 | 1 | 1 | IV |
| 5516.09* | 500d | 300r | II | 5564.29 | 2 | 1 | IV |
| 5517.03 | 1 | 1 | IV | 5565.60 | 4 | 4 | III |
| 5517.87 | 1— | 4 | III A | 5568.04 | 3d | 2 | IV |
| 5518.33 | 2 | 2 | IV | 5569.06 | 2 | 2 | IV |
| 5518.86 | 15 | 8 | III | 5569.27 | 5 | 6 | III |
| 5519.62 | 15 | 4 | IV | 5569.58 | 1 | 1 | IV |
| 5519.87* | 4? | 4 | IV | 5570.59 | 10 | 5 | III |
| 5521.65 | 6 | 2 | IV | 5572.02 | 2 | 1 | IV |

TABLE I—*Continued*

| λ | Intensity | | Class | λ | Intensity | | Class |
|---|---|---|---|---|---|---|---|
| | Arc | Furnace | | | Arc | Furnace | |
| 5573.42 | 100 | 60 | II | 5619.85 | 1d | 1 | IV |
| 5573.89 | 2 | 1 | IV | 5620.90 | 3 | 2 | IV |
| 5574.89 | 80 | 30 | II | 5621.79 | 200 | 100 | I |
| 5575.59 | 15 | 20 | I | 5622.01* | ? | 2 | IV |
| 5576.00 | 2 | 1 | IV | 5622.72 | 3 | 3 | IV |
| 5576.43 | 2 | 1 | IV | 5623.63 | 6d | 5 | IV |
| 5578.94 | 10 | 1 | IV | 5624.69 | 5 | 6 | III |
| 5579.41 | 1— | 2 | IV A | 5624.96 | 8 | ..... | V E |
| 5581.83* | 10d | 20 | II A | | | 5 | III |
| 5582.88 | 2 | 1 | IV | 5626.01 | 250 | 150r | II |
| 5583.25* | 20d | 4 | IV | 5627.70 | 8 | 6 | III |
| 5583.75 | 2 | 1 | IV | 5628.15 | 3 | 1 | IV |
| 5584.28 | 1 | 1 | IV | 5630.07 | 5 | 5 | III |
| 5585.16 | 2 | 3 | IV | 5630.85 | 3 | 2 | IV |
| 5585.62 | 2 | 1 | IV | 5631.79 | 3 | 2 | IV |
| 5587.02 | 2 | 3 | IV | 5632.06 | 3 | 2 | IV |
| 5587.46 | 5 | 4 | IV | 5632.36 | 3 | 4 | III |
| 5588.20 | 100 | 30 | II | 5633.06 | 4 | 2 | IV |
| 5589.13 | 3d | 4 | IV | 5633.53 | 8 | 5 | III |
| 5589.86* | 10d | 6 | III | 5634.22 | 2 | 2 | IV |
| 5591.17 | 20 | 40 | I A | 5636.70 | 2 | 1 | IV |
| 5591.68 | 20 | 6 | III | 5637.30* | 6 | ..... | V E |
| 5591.91 | 5 | 3 | III | 5638.67 | 3 | 2 | IV |
| 5595.39 | 3 | 3 | III | 5639.91 | 2 | 1 | IV |
| 5596.99 | 1 | 1 | IV | 5640.25 | 10 | 10 | III |
| 5597.57 | 4d | 2 | IV | 5641.59 | 8 | 10 | II |
| 5598.15 | 3 | 1 | IV | 5642.01 | 8 | 6 | III |
| 5598.68 | 4 | 2 | IV | 5642.67 | 6 | 20 | II A |
| 5599.56 | 3 | 2 | IV | 5642.91 | 8 | 3 | IV |
| 5600.26 | 1 | 1 | IV | 5643.36 | 2d | ..... | V E |
| 5600.86 | 30d | ..... | V E | 5644.10 | 200 | 20 | III |
| 5601.18 | 2 | 3 | IV | 5646.04 | 2 | 2 | IV |
| 5603.64 | 5 | 5 | III | 5647.47 | 8 | 15 | II A |
| 5604.70* | 2 | 2 | IV | 5649.01 | 10 | 5 | III |
| 5605.46 | 3 | 1 | IV | 5649.57 | 1d | 1 | IV |
| 5605.96 | 1d? | 1 | IV | 5650.39 | 8 | 4 | III |
| 5606.55 | 2 | 1 | IV | 5650.78 | 6 | 3 | IV |
| 5608.42 | 4d | 3 | IV | 5651.67 | 3 | 3 | IV |
| 5609.69 | 5 | 3 | III | 5651.95 | 4d | 5 | IV |
| 5610.00 | 4 | 1 | IV | 5652.84 | 30 | 40 | I |
| 5610.42 | 2 | 1 | IV | 5656.34 | 60 | 20 | III |
| 5611.30 | 3 | 1 | IV | 5657.20 | 6d | 4 | IV |
| 5611.46 | 2 | 1 | IV | 5657.89 | 3d | 1 | IV |
| 5611.88 | 4d | 1 | IV | 5658.16* | 4d | 2 | IV |
| 5612.99 | 4 | 5 | III | 5659.86 | 400 | 200r | II |
| 5614.39 | 4d | 2 | IV | 5661.10 | 8 | 8 | III |
| 5615.04 | 4 | 5 | III | 5661.54 | 2d | ..... | V E |
| 5615.74 | 5 | 3 | IV | 5663.91 | 40 | 10 | III |
| 5617.75 | 2 | 3 | IV | 5664.70 | 6 | 3 | IV |
| 5618.34 | 1d | 1 | IV | 5666.03 | 6d | 15 | III A |
| 5619.14 | 2d | 1 | IV | 5667.52 | 4 | 1 | IV |

TABLE I—*Continued*

| λ | Intensity | | Class | λ | Intensity | | Class |
|---|---|---|---|---|---|---|---|
| | Arc | Furnace | | | Arc | Furnace | |
| 5668.96 | 3d | 3 | IV | 5717.92 | 80 | 30 | III |
| 5670.75 | 8 | 3 | IV | 5719.16* | 8 | 3 | IV |
| 5672.38 | 2 | 1 | IV | 5720.19 | 125 | 60 | II |
| 5672.85 | 10d | 2 | IV | 5720.83 | 3 | 3 | IV |
| 5673.75 | 2d | 2 | IV | 5721.38* | 50d | 20 | III |
| 5674.08 | 3 | 2 | IV | 5724.45 | 15d | 8 | III |
| 5674.42 | 2 | 1 | IV | 5726.06 | 3 | 10 | II A |
| 5674.66 | 2d | 1 | IV | 5727.04* | 5 | 8? | III ? |
| 5676.06 | 12 | 6 | III | 5728.50 | 4 | 4 | III |
| 5678.74 | 3 | 15 | II A | 5729.30 | 30 | 20 | III |
| 5679.15 | 8 | 8 | IV | 5730.13* | 25d | 15 | III |
| 5679.98* | 3d | 2 | IV | 5731.37 | 1 | 1 | IV |
| 5680.85 | 8 | 8 | III | 5732.95 | 300 | 150 | II |
| 5682.42 | 2 | 1 | IV | 5733.43 | 2 | 2 | IV |
| 5683.90 | 1d | 1 | IV | 5733.57 | 8 | 3 | IV |
| 5685.03 | 2 | 1 | IV | 5734.56 | 2 | 1 | IV |
| 5686.84* | 15d | 5? | IV | 5735.00 | 10 | 6 | III |
| 5686.98 | 20 | 20 | I | 5736.33 | 2 | 1 | IV |
| 5687.67 | 5 | 2 | IV | 5736.69 | 5 | 5 | IV |
| 5688.20 | 5 | 1 | IV | 5736.84 | 15 | 10 | III |
| 5688.52 | 4 | 1 | IV | 5738.01 | 10d | ..... | V E |
| 5690.43 | 5d | 6 | IV | 5738.49 | 2 | 2 | IV |
| 5691.64 | 6 | 5 | IV | 5740.00 | 3 | 1 | IV |
| 5692.05 | 20 | 10 | III | 5740.89 | 20 | 8 | III |
| 5692.67 | 2 | 3 | IV | 5741.19* | 3d | 4 | I |
| 5693.68 | 8 | 10 | III | 5742.88 | 1 | 1 | IV |
| 5694.62 | 4 | 2 | IV | 5743.35 | 15d | ..... | V E |
| 5696.73 | 200 | 40 | III | 5745.06 | 6 | 4 | IV |
| 5698.91 | 5 | 3 | IV | 5745.50 | 30 | 20 | III |
| 5699.5 | 4? | 2 | IV | 5746.50 | 5 | 50 | II A |
| 5699.61 | 10 | 6 | III | 5747.54 | 2d | 1 | IV |
| 5700.26 | 3 | 1 | IV | 5748.09* | 30 | 12 | III |
| 5701.11 | 6d | 8 | III | 5748.44 | 5 | 4 | III |
| 5702.27 | 2 | 2 | IV | 5750.75 | 4 | 2 | IV |
| 5703.51 | 5 | 4 | III | 5751.38 | 4 | 3 | IV |
| 5705.72 | 4d | 3 | IV | 5752.18 | 1 | 1 | IV |
| 5706.20 | 300 | 100r | II | 5752.60 | 4 | 2 | IV |
| 5706.75 | 80 | 80 | I | 5753.12 | 3d | 3 | IV |
| 5707.22 | 3d | 25 | I A | 5754.34 | 2d | 1 | IV |
| 5707.86 | 1 | 2 | IV A | 5755.94 | 8 | 4 | III |
| 5708.34 | 3 | 1 | IV | 5756.41 | 12 | 8 | III |
| 5708.76 | 6 | 2 | IV | 5757.38 | 2 | 2 | IV |
| 5709.58 | 3 | 3 | IV | 5757.97 | 80 | 25 | III |
| 5709.73 | 15 | 6 | III | 5758.54 | 4 | 3 | IV |
| 5710.93 | 80 | 15 | III | 5758.88 | 4 | 2 | IV |
| 5711.45 | 40 | 60 | II | 5759.45 | 2d | 2 | IV |
| 5713.61 | 3 | 1 | IV | 5759.52 | 20 | ..... | V E |
| 5714.27 | 3d | 1 | IV | 5761.00 | 2 | 2 | IV |
| 5715.69 | 1 | 1 | IV | 5761.75 | 4 | 4 | IV |
| 5716.03 | 2 | 1 | IV | 5762.35 | 2 | 4 | IV A |
| 5716.50 | 3d | 1 | IV | 5763.3 | 2d | 2 | IV |

TABLE I—*Continued*

| λ | Intensity | | Class | λ | Intensity | | Class |
|---|---|---|---|---|---|---|---|
| | Arc | Furnace | | | Arc | Furnace | |
| 5763.48 | 5 | 8 | III | 5811.50 | 2 | 1 | IV |
| 5763.91 | 60 | 12 | III | 5812.53 | 4 | 1 | IV |
| 5764.31 | 2 | 1 | IV | 5812.66 | | .... | V E |
| 5765.02 | 8 | 6 | III | 5814.89* | 250 | 60 | II |
| 5765.57 | 2 | 1 | IV | 5816.34 | 20 | 12 | III |
| 5765.90 | 4 | 4 | III | 5818.32 | 30 | 20 | III |
| 5766.50 | 1 | 1 | IV | 5819.37 | 5 | 10 | III A |
| 5767.63 | 1 | 1 | IV | 5820.68 | 4 | ..... | V E |
| 5768.10 | 4d | 1 | IV | 5822.61 | 5 | 40 | I A |
| 5768.79 | 2 | 1 | IV | 5823.18 | 3 | 1 | IV |
| 5770.57 | 1 | 1 | IV | 5823.98 | 10 | 6 | III |
| 5771.54 | 2 | 1 | IV | 5825.50 | 4 | 3 | IV |
| 5771.73 | 6 | 4 | III | 5825.68* | 10 | 6 | III |
| 5773.77 | 250 | 30 | III | 5827.61 | 8 | 4 | III |
| 5774.02* | ? | 6 | III | 5829.72 | 4d | 4 | III |
| 5774.93 | 2d | 3 | IV | 5830.51 | 100 | 60 | III |
| 5778.33 | 150 | 50 | III | 5831.02 | 30 | ..... | V E |
| 5779.24 | 200 | 100 | I | 5831.74 | 10d | ..... | V E |
| 5780.35 | 2 | 3 | IV | 5832.62 | 2 | 2 | IV |
| 5780.86 | 2d | 3 | IV | 5833.39 | 8 | 4 | III |
| 5781.93 | 10 | ..... | V E | 5836.37 | 25d | ..... | V E |
| 5783.53 | 20 | 30 | III | 5836.60 | 8 | 6 | III |
| 5784.70 | 4 | 5 | III | 5838.05 | 1 | 3 | IV A |
| 5786.98* | 50 | ? | V E | 5838.43 | 8 | 6 | III |
| 5787.15 | 30 | 20 | III | 5839.27 | 2 | 3 | IV |
| 5787.53 | 20 | 15 | III | 5839.56 | 5 | 8 | III |
| 5788.38* | 200 | 80 | I | 5839.87 | 15d | 15 | III |
| 5789.88 | 3 | 2 | IV | 5841.98 | 3 | ..... | V E |
| 5790.05 | 1 | 1 | IV | 5842.60 | 15 | ..... | V E |
| 5790.31 | 3 | 1 | IV | 5843.76 | 30 | 12 | III |
| 5790.91 | 8 | 50 | I A | 5844.87 | 2 | 1 | IV |
| 5791.75 | 2 | 2 | IV | 5845.88 | 4 | 2 | IV |
| 5792.52 | 3 | 2 | IV | 5846.41 | 5 | 5 | III |
| 5793.20* | 3 | 2 | IV | 5846.57 | 10 | 6 | III |
| 5794.08 | 2 | 1 | IV | 5847.36 | 4d | 3 | IV |
| 5794.32 | 2 | 2 | IV | 5848.67 | 10d | ..... | V E |
| 5795.29 | 5 | 3 | IV | 5849.72 | 10 | 8 | III |
| 5796.45 | 2 | 1 | IV | 5851.02* | 4d | 4 | IV |
| 5797.33 | 3d? | 1 | IV | 5851.84 | 1 | 2 | IV A |
| 5797.87 | 4d | 2 | IV | 5852.02 | 3 | 2 | IV |
| 5798.59 | 3 | 1 | IV | 5853.07 | 10 | 4 | III |
| 5800.52 | 250 | 50 | III | 5853.48 | 2 | 1 | IV |
| 5801.24 | 30 | 15 | III | 5854.44 | 2 | 3 | IV |
| 5801.66 | 4d | 1 | IV | 5854.65 | 3d | 3 | IV |
| | | .... | V E | 5855.37 | 3 | 2 | IV |
| 5802.84 | 300 | 100 | I | 5855.97 | 3 | 2 | IV |
| 5803.12 | 5 | 3 | IV | 5857.10 | 15 | 4 | III |
| 5804.71 | 3 | 1 | IV | 5857.25 | 1 | 2 | IV A |
| 5806.77 | 30 | 20 | III | 5858.15* | 6 | 3 | IV |
| 5807.83 | 2 | 1 | IV | 5860.42 | 150d | ..... | V E |
| 5810.37 | 3 | 3 | III | | | 30 | III |

TABLE I—*Continued*

| λ | Intensity | | Class | λ | Intensity | | Class |
|---|---|---|---|---|---|---|---|
| | Arc | Furnace | | | Arc | Furnace | |
| 5860.78 | 4 | 40 | II A | 5905.58 | 2 | 1 | IV |
| 5861.39 | 2 | 1 | IV | 5906.05 | 50 | 40 | I |
| 5863.47 | 4d | ..... | V E | 5906.61 | 10 | 5 | III |
| 5863.88 | 2 | 1 | IV | 5908.54 | 2 | 1 | IV |
| 5864.49 | 20d | 15 | III | 5909.04 | 80 | 40 | I |
| 5866.23 | 1d | 20 | III A | 5909.51 | 2 | 1 | IV |
| 5867.45 | 10 | 15 | III | 5910.83 | 20d | 25 | III |
| 5867.79 | 250 | 80 | II | 5912.61 | 100 | 30 | III |
| 5868.61 | 200 | 125 | I | 5913.56 | 60 | 15 | III |
| 5869.12 | 1 | 1 | IV | 5913.86 | 4d | ..... | V E |
| 5870.04 | 2d | 2 | IV | 5914.91 | 12 | 40 | I A |
| 5870.33 | 5 | 6 | III | 5915.56 | 25 | 8 | III |
| 5871.06 | 150 | 125 | I | 5916.04 | 4 | 4 | III |
| 5874.21 | 200 | 150 | I | 5916.36 | 80 | 150 | I A |
| 5875.10 | 12 | 10 | III | 5917.97 | 5 | 5 | III |
| 5875.92 | 40 | 100 | I A | 5919.33 | 15d | ..... | V E |
| 5877.54 | 1 | 1 | IV | 5921.01 | 80 | 12 | III |
| 5878.11 | 3d | ..... | V E | 5921.29 | 6 | 5 | III |
| 5879.29 | 5 | 5 | III | 5921.80 | 3d | 3 | IV |
| 5879.57 | 6 | 4 | III | 5922.81 | 2 | 2 | IV |
| 5880.14 | 1 | 1 | IV | 5923.34 | 80 | 15 | III |
| 5880.52 | 3d | 2 | IV | 5924.23 | 20d | 25 | III |
| 5881.86* | 2 | 1 | IV | 5924.66 | 60 | 25 | III |
| 5882.52 | 12 | 6 | III | 5925.95 | 12d | 12 | III |
| 5883.68 | 10 | 50 | II A | 5926.44 | 6 | ..... | V E |
| 5884.36 | 1 | 1 | IV | 5927.89 | 20 | 60 | II A |
| 5885.54 | 2 | 1 | IV | 5928.35 | 5d | 4 | III |
| 5886.06 | 3 | 3 | IV | 5929.18 | 4d | 3 | IV |
| 5887.26 | 10 | 2 | IV | 5931.57 | 3 | 4 | III |
| 5888.05 | 3 | 2 | IV | 5932.18 | 60 | 25 | III |
| 5888.24 | 6 | 10 | III | 5932.43 | 6d | ..... | V E |
| 5888.96 | 3 | 1 | IV | 5932.90 | 6 | ..... | V E |
| 5890.61* | 8? | 15 | III A | 5935.12 | 6 | 6 | III |
| 5891.41 | 25 | 20 | III | 5935.58 | 10 | 10 | III |
| 5891.90 | 2 | 2 | IV | 5936.12 | 5d | ..... | V E |
| 5894.00 | 2 | 1 | IV | 5936.92 | 2d | 8 | II A |
| 5895.16 | 10 | 10 | III | 5938.86 } | 100d | { 20 | III |
| 5895.35* | 4? | 20 | I A | 5938.90 } | | { ..... | V E |
| 5896.28* | ? | 6 | III | 5939.99 | 2 | 2 | IV |
| 5896.55* | ? | 1 | IV | 5940.64 | 2 | 1 | IV |
| 5896.80 | 3 | 2 | IV | 5941.47 | 25d | 40 | III |
| 5897.39 | 15 | ..... | V E | 5942.14* | 2? | 4 | III A |
| 5896.96 | 150 | 30 | II | 5942.33 | 50 | 10 | III |
| 5899.75 | 2 | 1 | IV | 5942.56 | 2 | 1 | IV |
| 5900.71 | 6d | 5 | III | 5943.00 | 25 | 6 | III |
| 5901.38 | 4 | ..... | V E | 5944 48 | 1 | 3 | IV A |
| 5902.4 | 8d | ..... | V E | 5944.81 | 2d | 2 | IV |
| 5902.60 | 80 | 40 | I | 5946.37 | 80 | 30 | III |
| 5903.04 | 8d | 6 | III | 5947.45 | 6 | 4 | III |
| 5903.50 | 60d | 40 | III | 5949.14 | 20 | 25 | III |
| 5903.98 | 3d | 2 | IV | 5950.20 | 8 | 6 | III |

TABLE I—*Continued*

| λ | Intensity | | Class | λ | Intensity | | Class |
|---|---|---|---|---|---|---|---|
| | Arc | Furnace | | | Arc | Furnace | |
| 5952.12 | 2 | 1 | IV | 5997.32 | 6 | ..... | V E |
| 5953.30 | 2d | 1 | IV | 5998.08 | 6 | 5 | III |
| 5954.72 | 2d | 2 | IV | 5998.84 | 3 | 4 | III |
| 5955.68 | 15 | 3 | III | 6001.11 | 6 | 4 | III |
| 5955.82 | | ..... | V E | 6001.70 | 4 | ..... | V E |
| 5956.76 | 30 | 25 | III | 6001.94 | 60 | 40 | III |
| 5957.52 | 15 | ..... | V E | 6002.82* | 8d | 8 | III |
| 5958.21 | 10 | 8 | III | 6004.18 | 200 | 200 | I |
| 5959.49 | 20d | 20 | III | 6005.13 | 10d | 10 | III |
| 5960.09 | 100 | 40 | II | 6007.09 | 2 | 2 | IV |
| 5963.05 | 15 | 2 | IV | 6008.92 | 2 | 2 | IV |
| 5963.22 | | ..... | V E | 6009.89* | 15 | 20 | III |
| 5963.95 | 10 | 20 | III A | 6010.27 | 5 | 4 | III |
| 5964.28 | 1 | 2 | IV A | 6010.79 | 8 | 10 | III |
| 5965.12 | 1d | 1 | IV | 6011.22 | 30d | 12 | III |
| 5965.52* | 4? | 20 | III A | | | ..... | V E |
| 5965.71 | 50 | ..... | V E | 6012.85 | 3 | 2 | IV |
| 5966.39 | 2d | 3 | IV | 6013.53 | 5d | ..... | V E |
| 5966.96 | 6 | 15 | III A | | | 2 | IV |
| 5967.76 | 4d | 2 | IV | 6013.87 | 3 | 2 | IV |
| 5968.82 | 20d | ..... | V E | 6014.38 | 4d | 2 | IV |
| 5969.49 | 50 | 40 | III | 6014.62 | 10 | 15 | III |
| 5971.49 | 3d | 2 | IV | 6016.80 | 25 | 15 | III |
| 5972.15 | 4d | 2 | IV | 6017.39 | 8d | ..... | V E |
| 5972.56 | 5 | 4 | III | 6019.15 | 2 | 1 | IV |
| 5972.99 | 2 | 2 | IV | 6021.26 | 3 | ..... | V E |
| 5974.30 | 4 | 2 | IV | 6021.38 | 1 | 1 | IV |
| 5975.63 | 2 | 2 | IV | 6021.75 | 3 | ..... | V E |
| 5976.48 | 6 | 4 | III | 6022.07 | 1 | 2 | IV A |
| 5978.04 | 15 | 8 | III | 6023.21 | 5d | 10 | III A |
| 5979.38 | 200 | 200 | I | 6024.45 | 8d | 10 | III |
| 5979.76 | 3 | 2 | IV | 6024.6 | 1 | 1 | IV |
| 5980.36 | 3 | 2 | IV | 6025.18 | 2 | 1 | IV |
| 5980.53 | 6 | 6 | III | 6025.51 | 2 | 1 | IV |
| 5982.01 | 10 | 20 | III A | 6026.26 | 2d | 5 | III A |
| 5982.33 | 12 | 8 | III | 6026.83 | 2 | 4 | III A |
| 5983.21 | 4 | 6 | III | 6027.16 | 150 | 150 | I |
| 5983.63 | 10d | 20 | III A | 6027.52 | 40 | 100 | I A |
| 5983.88 | 10 | 15 | III | 6028.63 | 10 | 8 | III |
| 5984.29 | 150 | 30 | III | 6029.84 | 8 | 5 | III |
| 5985.48 | 4 | 4 | III | 6030.35 | 6 | 5 | III |
| 5986.13 | 3 | 2 | IV | 6032.46 | 10 | 6 | III |
| 5987.46 | 4 | 2 | IV | 6033.23 | 5 | ..... | V E |
| 5989.68 | 50 | 150 | I A | 6033.46 | 1 | 1 | IV |
| 5991.74 | 6 | 6 | III | 6033.83 | 4 | ..... | V E |
| 5994.64 | 8 | ..... | V E | 6035.56 | 20 | 8 | III |
| 5995.09 | 125 | 100 | I | 6036.45 | 8d | 3 | IV |
| 5995.31 | 8 | 15 | III A | 6038.52* | 4 | 5 | III |
| 5996.05 | 15 | 20 | III | 6040.33 | 2 | 1 | IV |
| 5996.65 | 1 | 1 | IV | 6041.40 | 200 | 40 | III |
| 5996.93 | 3 | 3 | IV | 6042.84 | 20 | 10 | III |

TABLE I—*Continued*

| λ | Intensity | | Class | λ | Intensity | | Class |
|---|---|---|---|---|---|---|---|
| | Arc | Furnace | | | Arc | Furnace | |
| 6043.34 | 6 | 12 | III A | 6094.09 | 8d | 20 | III A |
| 6044.68 | 2 | 1 | IV | 6095.24 | 6 | 12 | III A |
| 6045.00 | 300 | 150 | I | 6096.24 | 2d | 1 | IV |
| 6045.39* | 200 | 50 | II | 6096.55 | 6 | 80 | I A |
| 6046.40 | 2 | 1 | IV | 6096.78 | 40 | 20 | III |
| 6047.49 | 6 | 10 | III | 6098.30 | 10d | 10 | III |
| 6049.20 | 2 | 1 | IV | 6099.12 | 12d | 30 | III A |
| 6049.81 | 3 | ..... | V E | 6099.90 | 40 | 200 | I A |
| 6050.30 | 5 | 2 | IV | 6101.42 | 5 | 5 | III |
| 6052.07 | 4d | 4 | III | 6101.96* | 15d | 5 | III |
| 6053.11 | 10 | 20 | III A | 6103.37* | 30d | 30 | III |
| 6053.88* | 15 | 20 | III | 6103.72 | 3 | 3 | IV |
| 6056.59 | 8d | 15 | III A | 6103.95 | 3d | 15 | II A |
| 6057.27 | 10 | 4 | III | 6104.2 | 3 | 3 | III |
| 6057.69 | 20 | 30 | III | 6104.39 | 25 | 20 | III |
| 6058.45 | 2 | 2 | IV | 6104.82 | 3d | ..... | V E |
| 6059.88 | 15 | 20 | III | 6105.36 | 4 | 6 | III |
| 6060.60 | 1 | 1 | IV | 6107.13 | 3d | 2 | IV |
| 6060.73 | 3d | ..... | V E | 6109.00 | 2 | 2 | IV |
| 6061.20 | 10d | 15 | III | 6109.26 | 8 | 10 | III |
| 6061.84 | 15 | 8 | III | 6110.19 | 2d | ..... | V E |
| 6062.47 | 2d | 1 | III | 6110.66* | ? | 1 | IV E |
| 6063.67 | 6d | 15 | III A | | 30 | 3 | IV |
| 6065.08 | 1 | 2 | IV A | 6111.66 | 4 | 15 | III A |
| 6066.66 | 4d | 12 | III A | 6111.83 | 10 | 15 | III |
| 6067.40 | 10d | 20 | III A | 6112.98 | 25d | 25 | III |
| 6067.78 | 6 | ..... | V E | 6114.58 | 10 | ..... | V E |
| 6068.27* | 15 | 12 | III | 6114.73 | 10 | 10 | III |
| 6070.06 | 300 | 200 | I | 6115.75 | 4 | 10 | III A |
| 6071.02 | 1d | 1 | IV | 6117.05 | 1 | 1 | IV |
| 6071.64 | 2 | 3 | IV | 6117.6 | 2 | 2 | IV |
| 6074.98 | 15 | 20 | III | 6117.79 | 40 | 150 | I A |
| 6075.72 | 40d | 60 | III | 6121.81 | 3 | ..... | V E |
| 6077.87 | 4 | 4 | III | 6122.75 | 60 | 15 | III |
| 6080.07 | 4 | 4 | III | 6123.60 | 10d | ..... | V E |
| 6080.47 | 5 | 6 | III | 6124.88 | 8 | ..... | V E |
| 6082.12 | 2d | 1 | IV | 6124.95 | | 3 | IV |
| 6082.67 | 80 | 40 | III | 6125.44 | 2d | 2 | IV |
| 6084.12 | 400d? | 250 | I | | | 1 | IV |
| 6084.61 | 4 | 4 | III | 6126.33 | 30 | 40 | III |
| 6085.22 | 1 | 1 | IV | 6127.01 | 15 | 15 | III |
| 6087.70 | 2 | 1 | IV | 6127.73 | 2 | 2 | IV |
| 6088.09 | 10 | 12 | III | 6129.73 | 3 | 8 | III A |
| 6088.62 | 50 | 40 | III | 6130.43 | 3d | 5 | III A |
| 6089.29 | 4 | 4 | III | 6130.62 | 15 | 30 | III A |
| 6089.65 | 10 | 12 | III | 6131.16 | 15 | 20 | III |
| 6090.54 | 3 | 1 | IV | 6132.18 | 8 | 12 | III |
| 6091.40 | 100 | 50 | III | 6133.07 | 3 | 2 | IV |
| 6091.96 | 8 | 6 | III | 6133.24 | 8 | 20 | III A |
| 6092.94 | 10d | 20 | III A | 6134.69 | 3 | 2 | IV |
| 6093.69 | 8 | 15 | III A | 6135.85 | 100 | 50 | II |

TABLE I—*Continued*

| λ | Intensity | | Class | λ | Intensity | | Class |
|---|---|---|---|---|---|---|---|
| | Arc | Furnace | | | Arc | Furnace | |
| 6138.05 | 20d | 40 | III A | 6188.43 | 1 | 2 | IV A |
| 6138.48 | 10 | 10 | III | 6189.70 | 30d | 30? | III |
| 6139.33 | 30d | 30 | III | 6189.99 | 6d | 20? | III A |
| 6140.60 | 50 | 15 | III | 6190.62 | 1 | 1 | IV |
| 6143.09* | 10d | 5 | III | 6191.23* | 15d | 8 | III |
| 6143.59 | 40 | 20 | III | 6192.64* | 50d | 12 | III |
| 6143.95 | 25d | 30 | III | 6193.14 | 10 | 8 | III |
| 6144.74 | 4 | 2 | IV | 6194.39 | 200 | 200 | I |
| 6145.2 | 1 | 1 | IV | 6195.21 | 3d | 3 | IV |
| 6145.88 | 2 | 1 | IV | 6196.11 | 5 | 6 | III |
| 6146.53 | 25 | 20 | III | 6196.58 | 10 | 12 | III |
| 6147.30 | 2d | 4 | III A | 6196.83 | 2 | 25 | II A |
| 6148.27 | 10d | 8 | III | 6197.41 | 5 | 3 | IV |
| 6149.10 | 15d | ..... | V E | 6197.86 | 5 | 15 | III A |
| 6149.94 | 8 | 10 | III | 6198.14 | 5 | ..... | V E |
| 6150.94 | 6 | 8 | III | 6198.37 | 30 | 125 | I A |
| 6154.81 | 6d | 8 | III | 6198.78 | 2 | 2 | IV |
| 6156.90 | 8 | ..... | V E | 6199.47 | 3 | 3 | IV |
| 6157.55 | 6 | ..... | V E | 6200.08 | 8 | 8 | III |
| 6159.28 | 6 | 8 | III | 6200.53 | 2 | 2 | IV |
| 6159.56* | 150 | 200 | I | 6201.13 | 30 | 25 | III |
| 6160.42 | 12d | ..... | V E | 6202.7 | 2 | 1 | IV |
| 6162.25 | 10 | 4 | III | 6203.86 | 4 | 5 | III |
| 6163.16 | 2d | 8 | III A | | 100 | 10 | II |
| 6164.51 | 6d | ..... | V E | 6204.72 | 2 | 15 | II A |
| 6164.95 | 8 | 10 | III | 6205.83 | 15 | 12 | III |
| 6165.61 | 3d | 8 | III A | 6206.22 | 12 | 12 | III |
| 6165.84 | 50 | 20 | III | 6206.87 | 150 | 25 | III |
| 6166.62 | 2d | 5 | III A | 6207.13 | 50 | 15 | III |
| 6168.33 | 8d | ..... | V E | 6207.96 | 1 | 1 | IV |
| 6169.95 | 8 | 6 | III | 6209.02 | 12 | 5 | III |
| 6173.13 | 12d | 20 | III A | 6209.63 | 1 | 1 | IV |
| 6173.95 | 200 | 30 | III | 6210.48 | 15 | 12 | III |
| 6174.45 | 150 | 150 | I | 6210.75 | 15 | 15 | III |
| 6174.75 | 1 | 2 | IV A | 6212.65 | 4 | 5 | III |
| 6174.96 | 8d | ..... | V E | 6213.85 | 20 | 30 | III |
| 6176.40 | 6d | ..... | V E | 6215.13 | 1 | 2 | IV A |
| 6176.87 | 3d | 2 | IV | 6217.17* | 30d | 20 | III |
| 6177.46 | 20 | 15 | III | 6218.23 | 50 | 150 | I A |
| 6178.67 | 5d | 10 | III A | 6219.17 | 15 | 8 | III |
| 6179.41 | 100 | 25 | III | 6220.89* | 5 | 2 | IV |
| 6179.88* | 12d | 2 | IV | 6221.32 | 12d | 12 | III |
| 6181.05 | 12d | ..... | V E | 6222.55 | 15 | 30 | I A |
| 6181.57 | 3d | 2 | IV | 6222.74 | 5d | 4 | III |
| 6181.88 | 5d | ..... | V E | 6223.12 | 2d | 2 | IV |
| 6182.89 | 20d | ..... | V E | 6223.65 | 8 | 5 | III |
| 6184.54 | 1 | 1 | IV | 6225.26 | 8 | 8 | III |
| 6186.38 | 4 | 3 | IV | 6225.48* | 10 | 4 | III |
| 6186.87 | 4d | 3 | IV | 6226.3 | 1 | 1 | IV |
| 6187.94 6188.00 | 20 | 2 ..... | IV V E | 6226.70 | 100 | 20 | II |
| | | | | 6227.52 | 5d | 6 | III |

TABLE I—*Continued*

| λ | Intensity | | Class | λ | Intensity | | Class |
|---|---|---|---|---|---|---|---|
| | Arc | Furnace | | | Arc | Furnace | |
| 6228.31 | 5 | 4 | III | 6276.77 | 4 | 3 | IV |
| 6229.07 | 3 | 20 | II A | 6277.05 | 2d | 8 | III A |
| 6229.82 | 2 | 1 | IV | 6277.66 | 4 | 4 | III |
| 6230.41 | 1 | 1 | IV | 6279.06 | 3 | 1 | IV |
| 6231.70 | 6 | 3 | IV | 6279.62 | 20d | 20 | III |
| 6232.17 | 2 | 2 | IV | 6282.29 | 2 | 2 | IV |
| 6232.68 | 6 | 6 | III | 6283.25 | 1 | 2 | IV A |
| 6233.72 | 2 | 1 | IV | 6284.22 | 8d | 3 | IV |
| 6234.95 | 5 | 8 | III | 6285.18 | 30 | 60 | III A |
| 6235.36 | 10 | 10 | III | 6286.96 | 4 | 4 | III |
| 6236.24 | 8d | 6 | III | 6287.81 | 10d | 8 | III |
| 6236.95 | 3d | 1 | IV | 6288.28 | 4 | 4 | III |
| 6237.66 | 20d | ..... | V E | 6289.90 | 20d | ..... | V E |
| 6238.30 | 150 | 25 | III | 6290.78 | 8d | 25 | III A |
| 6240.49 | 20 | 15 | III | 6291.82 | 50d | ..... | V E |
| 6241.55 | 12d | 15 | III | 6292.94 | 150d | 100 | III |
| 6242.01 | 2 | 1 | IV | 6294.68 | 30d | ..... | V E |
| 6242.39 | 60 | 200 | I A | 6295.97 | 15 | 80 | II A |
| 6244.21 | 15d | ..... | V E | 6297.70 | 40d | 10 | III |
| 6245.30 | 2 | 1 | IV | 6299.62 | 4d | 8 | III A |
| 6245.71 | 4 | 6 | III | 6300.19 | 10 | ..... | V E |
| 6246.76 | 80d | ..... | V E | 6301.12 | 30d | ..... | V E |
| 6248.11 | 100 | 80 | III | 6301.24 | 1— | 2 | IV A |
| 6249.82 | 1 | 1 | IV | 6301.89 | 50 | 50 | III |
| 6251.73* | 20 | 20? | III A | 6302.40* | 25d | 2 | V E |
| 6253.89 | 3d | 4 | III | 6303.15 | 40 | ..... | V E |
| 6255.85 | 3 | 2 | IV | 6303.90 | 5d | 3 | IV |
| 6256.12 | 8 | 10 | III | 6304.74 | 4 | 2 | IV |
| 6256.54* | 20(?)d | 8 | III | 6305.19 | 15d | ..... | V E |
| 6256.66 | 100d | ..... | V E | 6306.33 | 15 | 8 | III |
| 6257.93 | 20 | 30 | III | 6307.06* | 60d | ..... | V E |
| 6258.94 | 4 | 30 | II A | 6308.28 | 10d | ..... | V E |
| 6260.12 | 30d | 20 | III | 6309.89 | 10 | 8 | III |
| 6260.47 | 1 | 2 | IV A | 6310.31 | 8 | 8 | III |
| 6261.16 | 3d | 4 | III | 6311.56 | 8 | 15 | III A |
| 6262.52 | 15 | 12 | III | 6313.20 | 5 | 3 | IV |
| 6264.32* | 8 | 3 | IV | 6313.83 | 3 | 4 | IV |
| 6265.66 | 8 | 4 | III | 6314.57* | 12 | 10 | III |
| 6266.34 | 3d | 3 | IV | 6315.78 | 8d | ..... | V E |
| 6267.28 | 150 | ..... | V E | 6316.94 | 8 | 5 | III |
| 6268.40 | 8d | 5 | III | 6317.40 | 6 | 5 | III |
| 6271.06 | 15 | 12 | III | 6317.81 | 15 | 15 | III |
| 6271.38 | 20 | 20 | III | 6319.14 | 6 | 2 | IV |
| 6271.53* | 3? | 12 | III A | 6319.49 | 2 | 2 | IV |
| 6272.42 | 10d | 15 | III | 6321.43 | 10 | 10 | III |
| 6273.29 | 50 | 80<br>100 | I A<br>I A | 6321.71<br>6321.75 | 30 | 4<br>..... | IV<br>V E |
| 6273.71 | 20 | 15 | III | 6322.51 | 100 | 50 | III |
| 6275.11 | 15 | 20 | III | 6324.98 | 1 | 2 | IV A |
| 6275.81 | 8 | 5 | III | 6325.54 | 20d | ..... | V E |
| 6276.48 | 2d | 8 | III A | 6326.08 | 1 | 4 | III A |

TABLE I—*Continued*

| λ | Intensity | | Class | λ | Intensity | | Class |
|---|---|---|---|---|---|---|---|
| | Arc | Furnace | | | Arc | Furnace | |
| 6326.28 | 8 | 4 | IV | 6383.66 | 4d | 4 | IV |
| 6327.47 | 200d | ..... | V E | 6384.31 | 10 | 12 | III |
| 6327.66 | 5 | 10 | III A | 6384.83 | 20 | 25 | III |
| 6328.01 | 100 | 40 | III | 6386.77 | 250 | 50 | III |
| 6328.84 | 8d | ..... | V E | 6387.79 | 4 | 100 | I A |
| 6329.37 | 12d | 3 | IV | 6388.06 | 10 | 10 | III |
| 6330.91 | 1 | 2 | IV A | 6389.85 | 150 | ..... | V E |
| 6331.72 | 15 | 15 | III | 6390.24 | 1d | 5 | III A |
| 6335.39 | 12 | 10 | III | 6390.68 | ? | 2 | IV |
| 6335.98 | 1 | 1 | IV | 6390.81 | 150 | ..... | V E |
| 6336.38 | 2d | 6 | III A | 6392.45 | 5 | 3 | IV |
| 6337.92* | 10d | 15 | III | 6393.24 | 1 | 4 | IV A |
| 6338.89 | 15 | 4 | IV | 6394.14 | 10d | 8 | III |
| 6339.73 | 10 | 40 | III A | 6394.97 | 10 | 6 | III |
| 6340.10* | 50 | 20 | III | 6395.43 | 8 | 12 | III |
| 6341.58 | 4 | 2 | IV | 6398.29 | 12d | ..... | V E |
| 6342.11 | 20d | 15 | III | 6398.48* | ? | 2 | IV |
| 6343.36 | 15 | 30 | III A | 6399.47 | 30d | 30 | III |
| 6344.37 | 1 | 1 | IV | 6399.86 | 15d | 10 | III |
| 6345.86 | 3d | 30 | III A | 6401.45* | 4 | 2 | IV |
| 6346.51 | 20 | 15 | III | 6402.23 | 8d | 4 | IV |
| 6348.94 | 25 | 20 | III | 6403.98* | 8d | 6 | III |
| 6349.23 | 25 | 12 | III | 6404.63 | 5 | 5 | III |
| 6351.29 | 4d | 3 | IV | 6405.58 | 15 | 20 | III |
| 6353.54* | 80d | 15 | III | 6406.24 | 20d | ..... | V E |
| 6354.29 | 2d | 2 | IV | 6408.06 | 6d | ..... | V E |
| 6355.35 | 100 | 50 | III | 6409.88 | 1 | 2 | IV A |
| 6357.18* | 100d | 15 | III | 6410.32 | 4 | 3 | IV |
| 6359.53 | 2d | 2 | IV | 6410.8 | 1 | 2 | IV A |
| 6361.28 | 1 | 1 | IV | 6411.41 | 60 | 30 | III |
| 6363.16 | 5 | 6 | III | 6414.27 | 2 | 2 | IV |
| 6363.66 | 2 | 2 | IV | 6415.51 | 1 | 2 | IV A |
| 6366.09 | 3 | 2 | IV | 6417.17 | 4d | 5 | III |
| 6366.26 | 8 | 5 | III | 6417.50 | 100d | ..... | V E |
| 6367.41 | 250 | 250 | I | 6418.46 | 1 | 2 | IV A |
| 6368.28 | 25 | ..... | V E | 6418.66 | 1 | 1 | IV |
| 6368.41 | | 6 | III | 6418.92 | 6 | 6 | III |
| 6370.23 | 2 | 2 | IV | 6420.40 | 3d | 4 | IV |
| 6370.59 | 2 | 1 | IV | 6421.79 | 2 | 4 | IV A |
| 6371.01 | 150 | 150 | I | 6423.64 | 1 | 5 | III A |
| 6371.89 | 5d | ..... | V E | 6424.25 | 4 | 10 | III A |
| 6372.70 | 3 | 3 | IV | 6424.70 | 1 | 1 | IV |
| 6373.29 | 4 | 60 | II A | 6425.13 | 1 | 4 | IV A |
| 6373.50 | 10 | 100 | II A | 6425.90 | 200 | 250 | I |
| 6374.00 | 3 | 3 | IV | 6426.64* | 200d | 8 | V E |
| 6374.63 | 4 | 2 | IV | | | | III |
| 6375.23 | 2d | 1 | IV | 6428.32 | 30d | ..... | V E |
| 6377.27* | 6d | 3 | IV | 6428.94 | 150 | 80 | III |
| 6378.08 | 15 | 8 | III | 6429.86 | 2 | 3 | IV |
| 6380.05 | 80 | 50 | II | 6431.00 | 30d | ..... | V E |
| 6380.70 | 50 | 30 | III | 6431.96 | 8d | ..... | V E |

TABLE I—*Continued*

| λ | Intensity | | Class | λ | Intensity | | Class |
|---|---|---|---|---|---|---|---|
| | Arc | Furnace | | | Arc | Furnace | |
| 6433.32 | 4 | 8 | III A | 6487.62, 6487.70 | 60 | ..... | V E |
| 6433.96 | 30 | 30 | III | | | 5 | IV |
| 6435.34* | 150 | 60 | II | 6487.94 | 3d | 8 | III A |
| 6437.62 | 60 | 60 | II | 6488.62 | 10 | 20 | III A |
| 6438.14 | 3 | 3 | IV | 6489.44 | 2d | 4 | IV A |
| 6439.32 | 5 | 10 | III A | 6490.21 | 3d | 3 | IV |
| 6441.54 | 2 | 3 | IV | 6490.82 | 60d | ..... | V E |
| 6442.03 | 2 | 1 | IV | 6491.28 | 15 | 100 | I A |
| 6442.55 | 1 | 2 | IV A | 6492.05 | 5d | 25 | II A |
| 6445.1 | 1 | 1 | IV | 6493.10 | 3 | 4 | IV |
| 6447.56* | 6 | 2 | IV | 6493.30 | 2 | 5 | III A |
| 6448.06 | 30 | 30 | III | 6493.92 | 3 | 4 | IV |
| 6448.35 | 10 | 10 | III | 6494.52 | 4 | 6 | III |
| 6450.45 | 20 | 25 | III | 6496.05, 6496.16 | 6 | ..... | V E |
| 6451.01 | 5d | 15 | III A | | | 2 | IV |
| 6452.08 | 150 | 30 | II | 6498.67 | 150d | ..... | V E |
| 6453.38 | 4 | 6 | III | 6501.00 | 25 | 100 | I A |
| 6453.89 | 4 | 6 | III | 6501.52 | 3 | 4 | IV |
| 6455.60 | 40d | ..... | V E | 6502.00 | 8d | ..... | V E |
| 6456.18, 6456.25, 6456.46 | 30 | 2 | IV | 6502.37 | 4 | 4 | IV |
| | | ..... | V E | 6502.57 | 2 | 3 | IV |
| | | 5 | III | 6503.25 | 2d | 3 | IV |
| 6457.55 | 100 | 20 | II | 6504.20 | 6d | 2 | IV |
| 6458.45 | 5 | 4 | III | 6505.45* | 8d | 6 | III |
| 6459.36 | 60 | 30 | III | 6507.13 | 4 | ..... | V E |
| 6459.78 | 8d | 15 | III A | 6509.44* | 50(?)d | 300 | I A |
| 6460.72 | 6d | 12 | III A | 6510.03 | 5 | 4 | IV |
| 6461.15 | 12 | 10 | III | 6511.80 | 2 | 3 | IV |
| 6463.12 | 4 | 8 | III A | 6512.30 | 6d | 8 | III |
| 6464.41 | 5 | 10 | III A | 6512.69 | 8d | ..... | V E |
| 6466.30 | 5 | 3 | IV | 6514.65 | 8 | 20 | III A |
| 6468.34 | 15 | 15 | III | 6516.17 | 20 | 15 | III |
| 6469.00 | 6 | 5 | III | 6520.40 | 6 | 8 | III |
| 6469.42 | 4 | 3 | IV | 6522.74 | 5 | 4 | IV |
| 6469.76 | 15 | 15 | III | 6523.17 | 3d | 2 | IV |
| 6470.46 | 20d | ..... | V E | 6525.52 | 6 | 4 | IV |
| 6470.70 | 3d | 4 | IV | 6525.76 | 2 | 3 | IV |
| 6471.59 | 200 | 60 | II | 6526.12 | 4 | 3 | IV |
| 6472.19* | ? | 2 | IV | 6526.64 | 8d | ..... | V E |
| 6472.34 | 300d | ..... | V E | 6528.02 | 200 | 250 | I |
| 6474.25 | 10 | ..... | V E | 6528.34 | 1 | 2 | IV A |
| 6476.45 | 15 | 20 | III | 6528.98 | 10 | 8 | III |
| 6477.02 | 10d | ..... | V E | 6529.70 | 150 | 100 | III |
| 6478.36 | 10d | 4 | IV | 6530.74 | 15 | 25 | III |
| 6479.25 | 8 | 10 | III | 6532.25 | 200 | 300 | I |
| 6481.3 | 1 | 2 | IV A | 6533.96 | 200 | 300 | I |
| 6483.39 | 25 | 50 | II A | 6535.35 | 5d | 3 | IV |
| 6483.96 | 3 | 2 | IV | 6536.83 | 30 | 150 | I A |
| 6484.48, 6484.52 | 200 | 4 | IV | 6537.61 | 8 | 5 | III |
| | | ..... | V E | 6537.93 | 3d | 2 | IV |

TABLE I—*Continued*

| λ | Intensity | | Class | λ | Intensity | | Class |
|---|---|---|---|---|---|---|---|
| | Arc | Furnace | | | Arc | Furnace | |
| 6539.92 | 4 | 6 | III | 6596.00 | 20 | 15 | III |
| 6540.72 | 4 | 5 | III | 6597.03 | 30d | 25 | III |
| 6541.13 | 5 | 5 | III | 6598.95 | 10d | 8 | III |
| 6542.76 | 150d | ..... | V E | 6600.39 | 3 | 4 | IV |
| 6543.29 | 4 | ..... | V E | 6601.83 | 100 | ..... | V E |
| 6544.52 | 40 | 4 | IV | 6603.53 | 20 | 8 | III |
| 6544.57* | | ..... | V E | 6604.56 | 300 | ..... | V E |
| 6544.66 | | 4 | IV | 6604.6 | | 2 | IV |
| 6544.95 | 40 | 150 | I A | 6605.7 | 4 | 2 | IV |
| 6547.60 | 2 | 2 | IV | 6607.17 | 6d | 4 | IV |
| 6547.88 | 2 | 2 | IV | 6608.4 | 2 | 3 | IV |
| 6549.50 | 1 | 2 | IV A | 6608.86 | 4 | 8 | III A |
| 6549.77 | 50d | ..... | V E | 6612.60 | 10 | 8 | III |
| 6551.04 | 6 | 5 | III | 6614.82 | 8d | ..... | V E |
| 6551.80 | 200 | 300 | I | 6616.80 | 10 | 10 | III |
| 6553.21 | 2 | 3 | IV | 6617.61 | 15 | ..... | V E |
| 6555.24 | 4d | 12 | III A | 6619.01 | 10 | ..... | V E |
| 6556.46 | 8 | 8 | III | 6622.67 | 8 | 8 | III |
| 6557.00 | 15 | ..... | V E | 6625.28 | 10 | ..... | V E |
| 6558.17 | 8 | 50 | I A | 6626.96 | 30d | 30 | III |
| 6558.39 | 4 | 5 | III | 6627.41 | 4d | 6 | III |
| 6562.64 | 10 | 80 | I A | 6627.83 | 10 | 6 | III |
| 6563.00 | 10 | 4 | IV | 6628.88 | 40d | ..... | V E |
| 6563.52 | 150 | 200 | I | 6629.71 | 10d | 6 | III |
| 6564.7 | 6d | 3 | IV | 6630.61 | 30d | ..... | V E |
| 6566.36 | 80 | 100 | I | 6631.46 | 4d | 8 | III A |
| 6567.50 | 5 | 10 | III A | 6632.28 | 100 | ..... | V E |
| 6569.31 | 1000d | 1? | V E | 6632.44 | | 8 | III |
| 6570.67 | 100d | ..... | V E | 6633.1 | 4d | ..... | V E |
| 6572.4 | 2 | 2 | IV | 6633.23 | | 3 | IV |
| 6573.03 | 20 | 30 | III | 6635.22 | 20 | 10 | III |
| 6574.38 | 30 | ..... | V E | 6635.36 | 4 | 3 | IV |
| 6575.95 | 5 | ..... | V E | 6637.17 | 15d | ..... | V E |
| 6577.36 | 4 | 2 | IV | 6638.49 | 4 | ..... | V E |
| 6579.31 | 4 | 4 | IV | 6639.32 | 6d | 6 | III |
| 6580.53 | 50 | 200 | I A | 6639.81 | 15 | 12 | III |
| 6581.25 | 8 | 4 | IV | 6640.49 | 12 | 10 | III |
| 6584.14 | 15 | 8 | III | 6640.74 | 12 | 6 | III |
| 6585.21 | 100d | ..... | V E | 6641.57 | 8 | 10 | III |
| 6585.66 | 4 | 3 | IV | 6643.88 | 15 | 10 | III |
| 6586.42 | 4 | 2 | IV | 6646.22 | 60d | 40 | III |
| 6587.54 | 50 | 25 | III | 6648.12 | 25 | 15 | III |
| 6588.41 | 40 | 30 | III | 6649.02 | 60 | ..... | V E |
| 6588.91 | 500 | 300 | I | 6649.13 | | 10 | III |
| 6589.56 | 400 | 12 | III | 6651.61 | 40 | ..... | V E |
| 6589.72 | | ..... | V E | 6654.30 | 10 | 4 | IV |
| 6590.20 | 10 | 20 | III A | 6656.19 | 50d | ..... | V E |
| 6591.02 | 2 | 3 | IV | 6661.37 | 50 | 40 | II |
| 6591.50* | 30 | 6 | III | 6661.63 | 15 | 5 | III |
| 6593.03 | 10 | 6 | III | 6667.22 | 30d | ..... | V E |
| 6594.7 | 3 | 2 | IV | 6667.43 | 4 | 2 | IV |

TABLE I—*Continued*

| λ | Intensity | | Class | λ | Intensity | | Class |
|---|---|---|---|---|---|---|---|
| | Arc | Furnace | | | Arc | Furnace | |
| 6667.83 | 4 | 2 | IV | 6728.24 | 20 | 6 | III |
| 6668.60 | 4 | 2 | IV | 6731.84 | 500d | ..... | V E |
| 6668.91 | 4 | 2 | IV | 6734.06 | 150d | ..... | V E |
| 6669.31 | 2d | 3 | IV | 6734.81 | 100d | ..... | V E |
| 6670.73 | 2 | 2 | IV | 6735.34 | 40d | ..... | V E |
| 6671.51* | 800 | 400 | I | 6735.82 | 8d | 5 | IV |
| 6672.20 | 3 | 3 | IV | 6737.30 | 2 | 4 | IV A |
| 6672.52 | 3 | 3 | IV | 6739.53 | 2 | 5 | II A |
| 6675.60 | 8d | 8 | III | 6741.2 | 4 | 2 | IV |
| 6677.06 | 30 | 20 | III | 6741.47* | 150d | ..... | V E |
| 6677.46 | 3 | 2 | IV | 6743.64 | 8 | 5 | III |
| 6678.00 | 6 | 60 | II A | 6746.14 | 2 | 2 | IV |
| 6679.1 } | 200 | 2 | IV | 6746.41 | 2 | ..... | V E |
| 6679.21 } | | ..... | V E | 6746.66 | 6 | 4 | III |
| 6679.69 | 4d | 8 | III A | 6748.39 | 10 | 4 | IV |
| 6681.53 | 30 | ..... | V E | 6750.86 | 10 | 4 | IV |
| 6682.57 | 20d | 6 | III | 6751.10 | 5 | 8 | III |
| 6685.02 | 4 | 2 | IV | 6754.68 } | 50 | ..... | V E |
| 6686.36 | 8 | 10 | III | 6754.85 } | | 8 | III |
| 6687.79 | 15d | ..... | V E | 6756.26 | 2d | 3 | IV |
| 6688.81 | 10 | 4 | IV | 6756.94 | 6d | ..... | V E |
| 6689.29 | 4 | 2 | IV | 6758.34 | 5 | 3 | IV |
| 6690.57 | 3 | 4 | IV | 6759.25 | 60 | 15 | III |
| 6690.8 | 2 | 3 | IV | 6761.70 | 5 | 2 | IV |
| 6692.57 | 3 | 4 | IV | 6764.22 | 15d | 10 | III |
| 6693.55* | 200d | 2 | V E | 6766.52 | 12d | ..... | V E |
| 6694.69 | 15 | ..... | V E | 6767.26 | 2 | 2 | IV |
| 6695.31 | 6 | 3 | IV | 6768.78 | 2 | 2 | IV |
| 6696.86 | 10 | 8 | III | 6769.44 | 10d | 5 | III |
| 6697.28 | 25 | 8 | III | 6771.36 | 20d | 20 | III |
| 6698.11 | 8 | 5 | III | 6772.02 | 20 | 6 | III |
| 6699.25 | 8d | 3 | IV | 6775.30 | 60 | 150 | I A |
| 6703.61 | 150 | 25 | III | 6778.19 | 40d | ..... | V E |
| 6704.25 | 40 | 20 | III | 6778.61 | 100 | ..... | V E |
| 6705.50 | 8 | 3 | IV | 6779.16 | 100 | 200 | I A |
| 6706.85 | 6 | 4 | IV | 6779.58 | 2 | 2 | III |
| 6707.1 | 2 | 2 | IV | 6780.03 | 4 | ..... | V E |
| 6709.33 | 6 | 4 | IV | 6781.17 | 20d | ..... | V E |
| 6711.51 | 12 | 5 | III | 6782.95 | 15 | ..... | V E |
| 6712.62 } | 30 | ..... | V E | 6790.00 | 200d | ..... | V E |
| 6712.8 } | | 1 | IV | 6790.27 | ? | 3 | III |
| 6713.86 | 10 | 4 | IV | 6790.88 | 30 | 60 | I A |
| 6717.15 | 15d | 4 | IV | 6791.43 | 6d | 3 | III |
| 6719.59 | 15 | 2 | IV | 6792.55 | 40d | ..... | V E |
| 6720.95 | 20d | 12 | III | 6792.90 | 6 | 5 | III |
| 6721.62 | 15 | 4 | IV | 6794.20 | 300 | ..... | V E |
| 6723.07 | 60 | 20 | III | 6795.08 | 2 | 2 | IV |
| 6723.26 | 50 | 12 | III | 6796.13 | 5 | 2 | IV |
| 6724.73 | 150 | 30 | III | 6796.82 | 30 | 15 | III |
| 6725.88 | 300 | 200 | I | 6797.59 | 3 | 2 | IV |
| 6727.27 | 10d | 20 | III A | 6799.59 | 2 | 3 | IV |

TABLE I—*Continued*

| λ | Intensity | | Class | λ | Intensity | | Class |
|---|---|---|---|---|---|---|---|
| | Arc | Furnace | | | Arc | Furnace | |
| 6801.34 | 1 | 3 | IV A | 6858.12 | 10 | 10 | III |
| 6801.72 | 8d | ..... | V E | 6860.93 | 800d | 300 | I |
| 6802.96 | 100 | 150 | I | 6861.10 | | ..... | V E |
| 6803.1 | 15d | 10 | III | 6862.82 | 150d | ..... | V E |
| 6804.89 | 4d | ..... | V E | 6865.91 | 1 | 2 | IV A |
| 6805.58 | 3 | 4 | IV | 6866.53 | 3d | ..... | V E |
| 6807.50 | 20 | 8 | III | 6867.11 | 20 | 20 | III |
| 6808.31 | 60 | 20 | III | 6868.13 | 2 | 4 | IV A |
| 6809.23 | 3 | 4 | IV | 6870.26 | 4d | ..... | V E |
| 6809.51 | 2 | 3 | IV | 6872.06 | 1 | 2 | IV A |
| 6813.4 | 20d | ..... | V E | 6872.43 | 100d | ..... | V E |
| 6813.54 | | 3 | IV | 6872.64* | ? | 3 | III A |
| 6814.86 | 5 | 6 | III | 6873.12* | ? | 3 | IV |
| 6815.54 | 8d | ..... | V E | 6873.26 | 6d | ..... | V E |
| 6816.16 | 8 | 4 | IV | 6873.69 | 4 | 5 | IV |
| 6819.72 | 2 | 5 | III A | 6875.27 | 20d | ..... | V E |
| 6820.91 | 40 | 15 | III | 6875.33* | ? | 2 | IV |
| 6821.90 | 12 | 6 | III | 6877.10 | 40 | ..... | V E |
| 6823.62 | 8 | ..... | V E | 6877.27 | | 5 | III |
| 6826.65 | 3 | 2 | IV | 6878.33 | 3 | ..... | V E |
| 6827.03 | 2 | 3 | IV | 6879.50 | 30 | 20 | III |
| 6827.81 | 20 | 150 | I A | 6880.86 | 10 | 200 | II A |
| 6828.50 | 10d | ..... | V E | 6881.57 | 1 | 2 | IV A |
| 6829.20 | 4 | 4 | IV | 6882.79 | 1 | 2 | IV A |
| 6829.86 | 150 | ..... | V E | 6883.11 | 1 | 1 | IV |
| 6830.54 | 30 | 25 | III | 6883.46 | 3 | 4 | III |
| 6831.37 | 1 | 1 | IV | 6884.92 | 10d | ..... | V E |
| 6832.13 | 2 | 3 | IV | 6885.16* | 100d | ..... | V E |
| 6834.40 | 2 | 1 | IV | 6887.42 | 40d | ..... | V E |
| 6835.02 | 1 | 2 | IV A | 6888.81 | 20 | 25 | III |
| 6835.97 | 2 | 3 | IV | 6891.48 | 40d | ..... | V E |
| 6837.20* | 25d | 12 | III | 6892.02 | 20 | ..... | V E |
| 6838.33 | 40 | 20 | III | 6895.55 | 3 | 5 | III |
| 6839.08 | 20d | ..... | V E | 6898.8 | 1 | 2 | IV A |
| 6839.23 | | 100 | II A | 6899.2 | 1 | 2 | IV A |
| 6839.64 | 20d | ..... | V E | 6899.8 | 1 | 2 | IV A |
| 6841.75 | 30 | 25 | III | 6900.28 | 15d | ..... | V E |
| 6844.71 | 200d | ..... | V E | 6904.51 | 10d | ..... | V E |
| 6845.74 | 6d | ..... | V E | 6906.22 | 50 | 15 | III |
| 6846.54 | 100d | ..... | V E | 6907.21 | 4 | 8 | III A |
| 6846.85* | ? | 4 | IV | 6907.45 | 2 | 2 | IV |
| 6848.16* | 80d | ..... | V E | 6909.81 | 60d | ..... | V E |
| 6848.31* | | 15 | III | 6911.44 | 3 | ..... | V E |
| 6848.88 | 15 | ..... | V E | 6912.78 | 5 | 100 | II A |
| 6852.94* | 2 | 2 | IV | 6913.54 | 3 | ..... | V E |
| 6853.54 | 15d | 10 | III | 6913.96 | 2 | 2 | IV |
| 6853.92 | 10 | 150 | II A | 6918.78* | 20 | 15 | III |
| 6854.50 | 40 | ..... | V E | 6919.03* | | 15 | III |
| 6855.73 | ? | 2 | IV | 6921.16 | 2 | ..... | V |
| 6856.03 | 400d | ..... | V E | 6921.77 | 2 | 3 | III |
| 6857.72 | 2d | ..... | V E | 6925.20 | 6 | 8 | III |

TABLE I—*Continued*

| λ | Intensity | | Class | λ | Intensity | | Class |
|---|---|---|---|---|---|---|---|
| | Arc | Furnace | | | Arc | Furnace | |
| 6925.70 | 3d | ..... | V E | 6975.99 | 5 | 15 | III A |
| 6926.14 | 5 | 25 | III | 6976.42 | 1d | ..... | V E |
| 6926.94 | 50 | 8 | III | 6977.55 | 5d | 20 | III A |
| 6927.03 | | ..... | V E | 6978.22 | 1 | 4 | IV A |
| 6927.70 | 4 | ..... | V E | 6978.46 | 2 | 2 | IV |
| 6928.18 | 2 | 5 | III | 6979.80 | 1— | 1 | IV A |
| 6928.84 | 4d | 12 | III A | 6980.0 | 1 | 2 | IV A |
| 6929.60 | 20d | ..... | V E | 6981.86 | 1— | 2 | IV A |
| 6930.41 | 40 | ..... | V E | 6982.7 | 1— | 1 | IV A |
| | | 3 | IV | 6984.16 | 30d | ..... | V E |
| 6932.1 | 1 | 3 | IV A | 6984.57 | 1 | 5 | IV A |
| 6933.7 | 1 | 2 | IV A | 6985.25 | 4 | 6 | III |
| 6934.29 | 4 | 12 | III A | 6985.67 | 6d | 30 | III A |
| 6935.38 | 6d | ..... | V E | 6987.36 | 4 | 5 | III |
| 6937.53 | 4 | ..... | V E | 6988.36 | 30 | 30 | II |
| 6938.39 | 1 | 4 | III A | 6988.91 | 1 | 1 | IV |
| 6938.74 | 15d | ..... | V E | 6989.23 | 1 | ..... | V |
| 6939.51 | 10 | 10 | III | 6990.08 | 20 | 25 | II |
| 6941.56 | 80 | ..... | V E | 6992.84 | 2 | 4 | III A |
| 6943.10 | 2d | 6 | III A | 6993.40 | 40 | ..... | V E |
| 6946.60 | 2 | 2 | IV | 6994.36 | 1 | 5 | IV A |
| 6948.18 | 3d | 12 | III A | 6995.38 | 3 | 4 | III |
| 6949.23 | 25d | ..... | V E | 6996.95 | 2 | 12 | III A |
| 6949.46 | ? | 10 | III | 6999.07 | 1 | 4 | IV A |
| 6850.15 | 2 | 8 | III A | 7000.31 | 1— | 2 | IV A |
| 6950.51 | 200d | ..... | V E | 7000.76* | 3 | 4 | III A |
| 6952.39* | 12d | 6 | IV | 7001.55 | 1 | 1 | IV |
| 6953.61 | 10 | 10 | III | 7002.03 | 2 | 60 | I A |
| 6954.32 | 4d | 10 | IV A | 7002.98 | 2 | 4 | III A |
| 6955.23 | 600 | 15 | III | 7003.98 | 1— | 4 | IV A |
| 6955.29 | | ? | V E | 7006.04 | 5 | 6 | IV |
| 6955.63* | 20d | 5 | III(V E) | 7007.39 | 20d | ..... | V E |
| 6957.73* | 3 | 15 | III A | 7008.41 | 6 | 6 | III |
| 6958.97 | 20 | ..... | V E | 7009.15 | 4 | 8 | IV A |
| 6960.98 | 1 | 1 | IV | 7009.67 | 20d | ..... | V E |
| 6961.92 | 1 | 3 | IV A | 7009.85 | | ..... | V E |
| 6962.83 | 1 | 4 | IV A | 7011.86 | 2d | 12 | III A |
| 6963.61 | 4d | 15 | IV A | 7012.99 | 4 | ..... | V E |
| 6964.8 | 1 | 2 | III A | 7013.60 | 4 | ..... | V E |
| 6965.95 | 12 | 25 | III A | 7014.60 | 2d | 4 | IV A |
| 6966.49 | 8 | 3 | III | 7015.36 | 5 | 4 | III |
| 6967.60 | 3 | ..... | V E | 7016.72 | 15 | 15 | II |
| 6968.65 | 40d | ..... | V E | 7018.04 | 1 | 4 | IV A |
| 6968.7 | ? | 3 | IV | 7018.93 | 5 | 4 | III |
| 6968.99 | 1 | 3 | III A | 7020.22* | ? | 5 | IV A |
| 6969.69 | 20d | ..... | V E | 7020.44 | 800d | ..... | V E |
| 6971.54 | 1 | 4 | IV A | 7022.68 | 12 | 12 | II |
| 6972.16 | 2 | 6 | III A | 7023.4 | 2d | 5 | III A |
| 6973.85 | 1 | 1 | IV | 7023.75 | 6 | 8 | II |
| 6974.74 | 2 | 5 | IV A | 7024.44 | 1— | 1 | IV |
| 6975.62 | 1 | 1 | IV | 7026.62 | 100 | 200 | I A |

TABLE I—*Continued*

| λ | Intensity | | Class | λ | Intensity | | Class |
|---|---|---|---|---|---|---|---|
| | Arc | Furnace | | | Arc | Furnace | |
| 7031.11 | 1 | 3 | IV A | 7092.98 | 10d | ..... | V E |
| 7032.31 | 1 | 2 | IV A | 7095.50 | 100 | 200 | I A |
| 7033.47 | 8 | 6 | III | 7096.33 | 40 | 150 | I A |
| 7034.67 | 8d | ..... | V E | 7099.20 | 1 | 1 | IV |
| 7036.73 | 50d | ..... | V E | 7100.77 | 5 | 2 | IV |
| 7037.08 | 1 | 4 | III A | 7101.46 | 10 | 50 | I A |
| 7037.56 | 1 | 1 | IV | 7102.00 | 10d | ..... | V E |
| 7037.9 | 1 | 2 | IV A | 7103.61 | 8 | 5 | III |
| 7038.76 | ? | 3 | IV | 7104.54 | 100 | 200 | I A |
| 7039.22 | 600d | ..... | V E | 7106.23 | 80 | 150 | I A |
| 7039.3 | ? | 8 | III | 7106.72 | 15d | ..... | V E |
| 7041.77 | 5? | 4 | III | 7107.88 | 1— | 2 | IV A |
| 7042.24 | 500d | ..... | V E | 7108.36 | 8d | ..... | V E |
| 7046.44 | 6 | 3 | III | 7109.06 | 4 | 4 | III |
| 7046.98 | 4d | 3 | IV | 7110.56 | 12 | 6 | III |
| 7047.82 | 4 | 2 | IV | 7111.44 | 6 | 2 | IV |
| 7049.15 | 40d | ..... | V E | 7112.34 | 1 | 1 | IV |
| 7051.44 | 500d | 40 | II | 7112.72 | 8d | ..... | V E |
| 7051.52 | | ..... | V E | 7114.50 | 10 | 80 | I A |
| 7053.54 | 10 | 10 | II | 7115.30 | 5 | 2 | IV |
| 7053.92 | 3 | 3 | IV | 7115.96 | 80 | 30 | II |
| 7054.97 | 50 | ..... | V E | 7117.51 | 60d | ..... | V E |
| 7055.1 | 1— | 2 | IV A | 7118.25 | 15 | 10 | II |
| 7056.55 | 40 | 40 | I | 7119.81 | 80 | ..... | V E |
| 7057.0 | 2 | 1 | IV | 7120.05* | ? | 6 | IV |
| 7057.28 | 2 | 4 | III A | 7122.40 | 15d | ..... | V E |
| 7059.37 | 5d | 4 | IV | 7122.6* | ? | 6 | III |
| 7060.02* | 2 | 3 | IV A | 7123.19 | 5d | 3 | III |
| 7060.3 | 4d | ..... | V E | 7123.29 | | ..... | V E |
| 7062.25 | 4 | 2 | IV | 7124.50 | 5d | 3 | IV |
| 7064.79 | 6 | ..... | V E | 7124.86* | ? | 2 | IV |
| 7065.02 | 15 | 8 | III | 7125.11 | 30d | ..... | V E |
| 7065.84 | 15d | ..... | V E | 7125.82 | 5 | 8 | III |
| 7066.1 | ? | 3 | IV | 7127.37 | 5 | 6 | III |
| 7066.86 | 1 | 3 | IV A | 7128.74 | 4 | 6 | III |
| 7067.38 | 10 | 10 | III | 7129.79 | 6d | 6 | III |
| 7069.32 | 2 | 2 | IV | 7131.80 | 60 | 150 | I A |
| 7071.10 | 8 | 5 | III | 7136.01 | 30 | 20 | II |
| 7074.41* | 15? | 8 | III | 7136.42 | 10 | 20 | II A |
| 7074.67 | 60 | 15 | II | 7137.58 | 4 | 3 | IV |
| 7076.88 | 2 | 3 | IV | 7137.99 | 3 | 4 | IV |
| 7079.48 | 10 | 10 | II | 7139.39 | 20d | ..... | V E |
| 7079.76 | 4 | 3 | III | 7141.13 | 30 | 100 | I A |
| 7082.37 | 400d | ..... | V E | 7142.09 | 4 | 4 | III |
| 7082.51 | ? | 3 | IV | 7143.98 | 40d | ..... | V E |
| 7082.98 | 4 | ..... | V E | 7147.70 | 5d | ..... | V |
| 7085.52 | 40d | ..... | V E | 7148.8 | 2 | 2 | III |
| 7088.30 | 50 | 250 | I A | 7149.60 | 150d | ..... | V E |
| 7089.94 | 4d | ..... | V E | 7151.03 | 4 | 4 | III |
| 7091.16 | 25 | 150 | I A | 7152.80 | 2 | 3 | IV |
| 7091.90 | 5d | ..... | V E | 7154.83 | 25 | 10 | II |

TABLE I—*Continued*

| λ | Intensity | | Class | λ | Intensity | | Class |
|---|---|---|---|---|---|---|---|
| | Arc | Furnace | | | Arc | Furnace | |
| 7155.4 | 1 | 3 | IV A | 7273.33 | 4d | ..... | V E |
| 7156.19 | 8 | 6 | II | 7273.88 | 20 | 8 | III |
| 7157.33 | 4 | 2 | IV | 7277.10 | 10 | 4 | IV |
| 7165.37 | 1— | 3 | IV A | 7278.84 | 2 | ..... | V |
| 7166.59 | 1 | 4 | IV A | 7279.25 | 60 | 100 | I |
| 7170.58 | 5d | ..... | V E | 7281.15 | 2 | 1 | IV |
| 7172.24 | 4 | 3 | IV | 7281.47 | 100d | ..... | V E |
| 7172.67 | 40 | 30 | I | 7282.21 | 20 | 4 | IV |
| 7174.0 | 1 | 2 | IV A | 7282.94 | 3 | 2 | IV |
| 7176.0 | 1— | 3 | IV A | 7283.33 | 40d | ..... | V E |
| 7179.67 | 6d | 4 | IV | 7284.61 | 2d | ..... | V E |
| 7180.85 | 3 | 5 | III | 7285.40 | 2 | ..... | V |
| 7181.60 | 5 | 4 | IV | 7286.30 | 1 | ..... | V |
| 7186.35 | 8 | 2 | IV | 7288.92 | 40 | ..... | V E |
| 7189.57 | 30d | ..... | V E | 7290.23 | 60 | 15 | II |
| 7191.63 | 3 | 3 | IV | 7291.52 | 3 | 1 | IV |
| 7193.9 | 1 | 3 | IV A | 7295.48 | 5d | ..... | V E |
| 7204.09 | 10 | 5 | IV | 7296.12 | 1 | ..... | V |
| 7210.95 | 30 | 20 | II | 7298.04 | 6d | 3 | IV |
| 7213.82 | 80 | 100 | I | 7298.4 | 2d | 1 | IV |
| 7215.08 | 4d | ..... | V E | 7300.72 | 60d | ..... | V E |
| 7216.00 | 8d | ..... | V E | 7304.16 | 3d | ..... | IV |
| 7218.09 | 40d | ..... | V E | 7304.74 | 8d | 1 | IV |
| 7218.28* | ? | 6 | III | 7306.58 | 2 | ..... | V |
| 7219.34 | 3 | 2 | IV | 7309.02 | 8 | 2 | IV |
| 7220.07 | 50 | 15 | II | 7309.35 | 4 | 1 | IV |
| 7221.14 | 6 | 10 | III | 7310.10 | 2 | 1 | IV |
| 7224.56 | 6d | 4 | IV | 7312.60 | 2d | 1 | IV |
| 7225.62 | 25 | 25 | II | 7314.00 | 4 | 1 | IV |
| 7227.15 | 10d | ..... | V E | 7316.31 | 10 | 5 | IV |
| 7228.91 | 8 | 3 | IV | 7317.77 | 4d | ..... | V |
| 7234.40 | 6 | 6 | III | 7318.70 | 1 | ..... | V |
| 7234.72 | 12 | ..... | V E | 7323.88 | 2d | ..... | V E ? |
| 7235.73 | 12 | ..... | V E | 7325.44 | 8d | ..... | V E |
| 7237.02 | 40d | ..... | V E | 7327.08 | 4d | ..... | V E |
| 7238.17 | 1 | 1 | IV | 7331.33 | 2d | ..... | V E |
| 7240.90 | 200 | ..... | V E | 7332.65 | 60 | 100 | I |
| 7244.73 | 3 | 3 | IV | 7335.10 | 8 | 4 | IV |
| 7245.60 | 6 | 6 | III | 7335.92 | 3d | ..... | V E |
| 7249.02 | 8d | ..... | V E | 7338.04 | 20d | 6 | IV |
| 7254.17 | 3 | 3 | IV | 7338.80 | 2 | ..... | V |
| 7254.95 | 15d | ..... | V E | 7344.76 | 12d | ..... | V E |
| 7256.18 | 4d | ..... | V E | 7347.30 | 150 | 8 | IV |
| 7257.11 | 25d | ..... | V E | 7354.09 | 3d | ..... | V E |
| 7261.45 | 10d | ..... | V E | 7355.99 | 1d | ..... | V E ? |
| 7262.69 | 3 | 20 | II A | 7358.37 | 1 | 1 | IV |
| 7263.59 | 2 | 2 | IV | 7362.70 | 3d | ..... | V E ? |
| 7264.4* | 6 | 2 | IV | 7363.01 | 8d | ..... | V E |
| 7268.45 | 3d | ..... | V E | 7364.10 | 20d | 15 | III |
| 7270.54 | 8d | ..... | V E | 7366.06 | 3d | ..... | V E |
| 7271.32 | 12 | ..... | V E | 7367.9 | 1— | 4 | II A |

TABLE I—*Continued*

| λ | Intensity | | Class | λ | Intensity | | Class |
|---|---|---|---|---|---|---|---|
| | Arc | Furnace | | | Arc | Furnace | |
| 7371.12 | 2 | ..... | V | 7502.39 | 50d | ..... | V E |
| 7371.51 | 30 | 5 | IV | 7503.38 | 6d | ..... | V E |
| 7373.31 | 1 | ..... | V | 7505.80 | 10d | ..... | V E |
| 7373.80 | 8d | ..... | V E | 7507.85 | 12 | ..... | V |
| 7375.14 | 3 | ..... | V | 7513.33 | 2 | 8 | II A |
| 7376.69 | 150 | ..... | V E | 7517.00 | 30d | ..... | V E |
| 7378.04 | 5 | 60 | I A | 7518.32 | 15d | ..... | V E |
| 7378.69 | 6 | ..... | V E | 7519.91 | 15 | ..... | V |
| 7383.55 | 15 | 2 | IV | 7520.90 | 20 | 2 | IV |
| 7385.42 | 4 | ..... | V | 7530.22 | 8d | ..... | V |
| 7387.12 | 4d | ..... | V E | 7531.35 | 10 | ..... | V |
| 7389.03 | 6 | 2 | IV | 7533.3 | 6d | 2 | IV |
| 7393.37 | 10 | ..... | V | 7534.2 | 6d | ..... | V |
| 7393.98 | 50d | ..... | V E | 7540.04 | 20d | ..... | V E |
| 7397.92 | 2 | 1 | IV | 7541.42 | 100d | ..... | V E |
| 7398.94 | 6 | ..... | V | | | 4 | III |
| 7401.23 | 6d | ..... | V E | 7543.62 | 15 | 6 | IV |
| 7402.38 | 6d | ..... | V E | 7544.74 | 50 | 6 | IV |
| 7403.30 | 8 | 60 | I A | 7546.57 | 20 | 5 | IV |
| 7405.00 | 60 | 10 | III | 7554.08 | 8 | 60 | I A |
| 7410.73 | 30 | 1 | IV | 7560.15 | 20d | ..... | V E |
| 7412.24* | 20 | ..... | V E | 7562.7 | ? | 2 | IV |
| 7417.02 | 10 | 2 | IV | 7562.94 | 50d | ..... | V E |
| 7418.71 | 6d | 3 | IV | 7563.85 | 15 | 10 | III |
| 7423.81 | 6d | ..... | V | 7570.95 | 150d | ..... | V E |
| 7424.43 | 6d | ..... | V | 7572.29 | 80d | ..... | V E |
| 7431.18 | 12d | 1 | IV | 7573.8 | 3 | 6 | IV A |
| 7434.14 | 5 | ..... | V | 7578.09 | 60d | ..... | V E |
| 7439.62 | 3d | ..... | V E ? | 7580.19 | 8d | ..... | V |
| 7440.44 | 6 | ..... | V | 7580.82 | 5 | 60 | I A |
| 7440.80 | 5 | ..... | V | 7580.91 | 6 | ..... | V E |
| 7442.00 | 10 | ..... | V | 7582.86 | 6 | 1 | IV |
| 7444.56 | 200 | 10 | IV | 7585.77 | 60d | ..... | V E |
| 7445.41 | 150 | 2 | IV | | | 2 | IV |
| 7446.2 | 1— | 5 | II A | 7588.31 | 40d | ..... | V E |
| 7449.28 | 15 | 2 | IV | 7590.04 | 20 | 15 | III |
| 7451.96 | 8 | ..... | V | 7590.43 | 25 | 25 | II |
| 7452.80 | 25d | ..... | V E | 7592.55 | 4 | 2 | IV |
| 7453.03 | 50d | ..... | V E | 7598.01 | 40 | 8 | II |
| 7454.38 | 10d | ..... | V E | 7607.48 | 40d | ..... | V E |
| 7454.70 | 3 | ..... | V | 7607.74 | 80 | 30 | III |
| 7460.52 | 20 | 2 | IV | 7610.78 | 8d | ..... | V E |
| 7470.76 | 80 | 30 | II | 7613.94 | 30d | ..... | V E |
| 7479.40 | 30 | 15 | II | 7619.33 | 5 | 2 | IV |
| 7479.96 | 20 | ..... | V E | 7623.16 | 15d | 10 | IV |
| 7481.99 | 60d | ..... | V E | 7629.24 | 3 | ..... | V |
| 7491.84 | 4 | ..... | V | 7631.77 | 20d | ..... | V E |
| 7494.07 | 25d | ..... | V E | 7637.94 | 60d | ..... | V E |
| 7497.26 | 8 | ..... | V | 7639.64 | 8 | 1 | IV |
| 7498.71 | 6 | ..... | V | 7643.01 | 30d | ..... | V E |
| 7499.50 | 15d | ..... | V E | 7643.91 | 40 | 6 | IV |

TABLE I—*Continued*

| λ | Intensity | | Class | λ | Intensity | | Class |
|---|---|---|---|---|---|---|---|
| | Arc | Furnace | | | Arc | Furnace | |
| 7645.09 | 200d | ..... | V E | 7789.76 | 15d | ..... | V E |
| 7645.82 | 80 | 30 | II | 7792.33 | 10 | ..... | V |
| 7648.02 | 100d | ..... | V E | 7792.76 | 3 | 10 | III A |
| 7655.78 | 50d | ..... | V E | 7794.50 | 100 | 25 | II |
| 7661.30 | 15 | ..... | V | 7798.47 | 10 | 2 | IV |
| 7662.94* | 20? | 10 | III | 7801.54 | 150 | 100 | II |
| 7667.20 | 50d | ..... | V E | 7805.56 | 8d | 4 | IV |
| 7668.21 | 20 | 3 | IV | 7806.11 | 30d | ..... | V E |
| 7670.40 | 20d | 4 | IV | 7808.21 | 5 | 3 | IV |
| | | ..... | V E | 7808.96 | 20d | ..... | V E |
| 7672.49 | 50 | ..... | V E | 7812.75 | 60d | 4 | V E |
| 7675.35 | 6d | ..... | V E ? | 7813.61 | 20d | ..... | V E |
| 7676.19 | 6d | ..... | V E ? | 7815.00 | 6d | ..... | V |
| 7678.79 | 60d | ..... | V E | 7820.15 | 150d | ..... | V E |
| 7680.51 | 5d | ..... | V E ? | 7823.34 | 8 | 6 | IV |
| 7686.07 | 4 | ..... | V | 7831.40 | 60d | ..... | V E |
| 7686.70 | 8 | 60 | I A | 7835.08 | 400d | ..... | V E |
| 7690.75 | 20d | ..... | V E | 7835.51 | 8 | 10 | II |
| 7691.34 | 15 | 3 | IV | 7835.99 | 3 | 4 | III ? |
| 7692.24 | 20d | 6 | IV | 7837.27 | 400 | ..... | V E |
| 7695.78 | 100 | 8 | IV | 7844.82 | 60d | ..... | V E |
| 7705.37 | 6 | ..... | V | 7846.10 | 4d | 2 | V E |
| 7709.14 | 8 | 2 | IV | 7848.77 | 10d | ..... | V E |
| 7710.72 | 10 | 3 | IV | 7854.94 | 12d | ..... | V E |
| 7712.04 | 60d | ..... | V E | 7856.10 | 8 | 10 | III |
| 7714.99 | 6 | 2 | IV | 7856.80 | 8d | ..... | V |
| 7715.71 | 5 | 1 | IV | 7859.53 | 100 | 30 | III |
| 7721.38 | 5 | 2 | IV | 7863.65 | 100d | ..... | V E |
| 7725.66 | 3 | 2 | IV | 7868.28 | 20d | 2 | IV |
| 7728.56 | 200d | ..... | V E | 7873.72 | 25d | ..... | V |
| 7732.54 | 4d | ..... | V E ? | 7875.10 | 20d | ..... | V E |
| 7735.5 | 2 | 2 | IV | 7880.07 | 100d | ..... | V E |
| 7736.26 | 150d | ..... | V E | | | 2? | IV |
| 7743.67 | 5 | 3 | IV | 7889.33* | 15 | 10? | III |
| 7746.94 | 5 | 2 | IV | 7895.96 | 250 | 50 | II |
| 7749.30 | 200 | ..... | V E | 7906.37 | 30d | ..... | V E |
| 7755.20 | 125d | ..... | V E | 7907.48 | 5 | 40 | I A |
| 7755.32* | ? | 80 | I A | 7913.49 | 60 | 10 | III |
| 7757.23 | 5 | 3 | IV | 7914.96 | 200d | ..... | V E |
| 7757.74 | 20d | ..... | V E | 7919.44 | 80 | 10 | III |
| 7758.20 | 5 | 3 | IV | 7921.34 | 15 | 1? | IV ? |
| 7766.99 | 4 | 1 | IV | 7926.27* | 30 | 15? | III ? |
| 7768.04 | 20d | 2 | IV | 7926.94 | 20d | ..... | V E |
| | | ..... | V E | 7928.14 | 800 | ..... | V E |
| 7771.6 | 2 | 1 | IV | 7931.15 | 50 | 15 | II |
| 7772.4 | 2 | 1 | IV | 7931.92 | 250 | 50 | II |
| 7772.83 | 30d | ..... | V E | 7934.01 | 10d | ..... | V E |
| 7777.01 | 30 | 15 | II | 7937.09 | 100d | ..... | V E |
| 7778.15 | 4 | 12 | II A | 7940.31 | 150 | 150 | I |
| 7782.51 | 4 | 1 | IV | 7946.15 | 10 | 2 | IV |
| 7783.77 | 5 | 8 | IV | 7947.00 | 15d | ..... | V E ? |
| 7787.02* | 8 | 60 | IA | 7948.12 | 100d | ..... | V E |

TABLE I—*Continued*

| λ | Intensity | | Class | λ | Intensity | | Class |
|---|---|---|---|---|---|---|---|
| | Arc | Furnace | | | Arc | Furnace | |
| 7952.22 | 12 | 2 | IV | 8208.25 | 60 | 8 | III |
| 7955.52 | 6 | ..... | V | 8214.74 | 5 | ..... | V |
| 7968.32* | 50 | 40? | III | 8218.61 | 300 | 150 | II |
| 7979.18 | 3 | ..... | V | 8218.76 | | ..... | V E |
| 7984.07 | 6 | ..... | V | 8230.33 | 100 | 5 | IV |
| 8001.61 | 200d | ..... | V E | 8240.98 | 150 | ..... | V E |
| 8005.00 | 15d | ..... | V E | 8246.51 | 10d | ..... | V E |
| 8014.92 | 200d | ..... | V E | 8248.2 | 5 | 6 | III |
| 8016.17 | 80 | 8 | IV | 8256.5* | 4 | —? | V ? |
| 8019.56 | 30 | 8 | IV | 8267.45 | 40d | 100 | I A |
| 8021.54* | 40 | 6? | IV | 8289.26 | 125d | ..... | V E |
| 8025.12 | 400 | ..... | V E | 8298.46* | 8 | ? | IV ? |
| 8026.32 | 500d | ..... | V E | 8300.88 | 80d | ..... | V E |
| 8027.58 | 1— | 15 | II A | 8301.34 | 100 | 200 | I A |
| 8029.56 | 6d | ..... | V E | 8305.79 | 500d | ..... | V E |
| 8032.03 | 250d | ..... | V E | 8312.71 | 15d | ..... | V |
| 8033.69 | 5 | ..... | V | 8315.45 | 150 | 150 | I |
| 8038.38 | 4 | ..... | V | 8320.09 | 6 | ..... | V |
| 8040.27* | 12d | ? | V ? | 8325.38* | 10 | 2? | IV ? |
| 8048.70 | 400 | ..... | V E | 8344.63 | 5 | ..... | V |
| 8055.50 | 8d | ..... | V E | 8348.68 | 150d | ..... | V E |
| 8065.16 | 150 | 150 | I | 8355.23 | 10d | ..... | V E |
| 8068.46 | 800 | ..... | V E | 8369.08 | 5d | ..... | V |
| 8070.37 | 50d | ..... | V E | 8372.26 | 25d | ..... | V E |
| 8071.74 | 40d | ..... | V E | 8383.71* | 150d | 100 | II |
| 8076.26 | 15 | ..... | V | 8387.77 | 100d | ..... | V E |
| 8084.52 | 15d | ..... | V E | 8390.30* | 15d | 2 | IV |
| 8087.08 | 15d | ..... | V E | 8393.86 | 15d | 30 | II A |
| 8090.80 | 60 | 30 | II | 8425.56 | 8d | ..... | V |
| 8091.15* | 80 | ? | IV ? | 8427.1 | 8d | ..... | V |
| 8102.38* | 20 | 8? | IV | 8432.64 | 250d | ..... | V E |
| 8112.31 | 4 | ..... | V | 8437.65 | 15d | 8 | III |
| 8116.20 | 12 | ..... | V | 8449.8 | 10d | 5 | III |
| 8117.16 | 150d | ..... | V E | 8454.76 | 20 | 20 | II |
| 8121.35 | 15 | ..... | V | 8457.77 | 30d | ..... | V E |
| 8122.29* | 6 | 1? | IV ? | 8465.08 | 8 | ..... | V |
| 8125.12 | 125d | ..... | V E | 8472.9 | 4 | 10 | II A |
| 8129.11 | 15 | 1 | IV | 8473.54 | 100d | ..... | V E |
| 8132.01* | 10 | 1? | IV ? | 8485.99 | 400d | ..... | V E |
| 8133.67 | 10d | ..... | V E ? | 8506.77 | 10d | ..... | V |
| 8135.27* | 5 | 2? | IV ? | 8510.90 | 200d | ..... | V E |
| 8146.60 | 40 | 100 | II A | 8539.22 | 10d | ..... | V |
| 8153.85 | 6 | ..... | V | 8543.22 | 150d | ..... | V E |
| 8161.90 | 200d | ..... | V E | 8568.94 | 8d | ..... | V |
| 8165.38 | 25d | ..... | V E | 8617.03 | 50d | ..... | V E |
| 8172.96 | 6d | ..... | V E | 8622.27 | 15d | ..... | V E ? |
| 8180.34 | 6d | ..... | V E ? | 8632.82 | 40d | ..... | V E |
| 8184.43 | 50d | ..... | V E | 8677.93 | 30d | ..... | V E ? |
| 8186.31 | 40d | ..... | V E | 8706.32* | 30 | ..... | V |
| 8195.50 | 200d | ..... | V E | 8708.43 | 60d | ..... | V E ? |
| 8203.98 | 80 | 150 | I A | 8717.89 | 50d | ..... | V E ? |
| 8206.30 | 80d | ..... | V E | | | | |

## NOTES TO TABLE I

| λ | |
|---|---|
| 2995.874 | Red component *Sa* II. |
| 3098.185 | Blend *Sa* II in arc? |
| 3192.012 | Furnace line may be *Ti*. |
| 3201.805 | Violet component stronger. |
| 3206.018 | Blend *Sa* II in arc. |
| 3253.015 | Probably blend *Sa* I to violet. |
| 3262.579 | Arc line partly *Sa* II. |
| 3290.285 | Violet component *Sa* I. |
| 3300.978 | Probably blend *Sa* I, *Sa* II. |
| 3343.640 | Red component *Sa* I. |
| 3345.394 | Faint *Sa* II to violet. |
| 3363.167 | Faint *Sa* II to violet. |
| 3384.857<br>3385.017 | Measured in furnace. Blend of four faint lines in arc. |
| 3420.510 | Blend in arc with *Sa* II to violet. |
| 3422.768 | Blend in arc with *Sa* II to red. |
| 3481.523 | Faint *Sa* II pair to violet. |
| 3487.3 | Blend in arc with λ 3487.409. |
| 3571.785 | Blend *CN* in furnace. |
| 3589.301 | Blend *CN* in furnace. |
| 3592.497 | Blend in arc with λ 3592.603 |
| 3651.516 | Arc line partly *Sa* II. Strong in spark. |
| 3653.462 | Blend *Ti* in furnace. |
| 3668.170 | Blend *Sa* II to violet in arc. |
| 3680.983 | Blend *Sa* II to violet in arc. |
| 3682.551 | Partly resolved. Strong in spark. |
| 3688.418<br>3724.902 | These lines blend with strong lines of *Eu* II, but appear to be chiefly *Sa*. |
| 3729.754 | Blend *Ti* in furnace. |
| 3739.362<br>3739.42 | Blend. Measured in arc and furnace, respectively. |
| 3755.352 | Blend λ 3755.276 in arc. |
| 3757.529 | Possibly a blend with *Sa* I. |
| 3760.785 | Blend λ 3760.694 in arc. |
| 3787.203 | Blend *CN* at high temperature. |
| 3799.542 | Blend *CN* at high temperature. |
| 3814.631 | Blend *CN*. Faint if present in furnace. |
| 3822.972 | Blend *CN* at high temperature. |
| 3834.604 | Blend *CN* in furnace. |
| 3848.779 | Blend *CN* in furnace. |
| 3854.556 | Blend *CN*. *Sa* I component probably strong. |
| 3858–3883 | Many intensities uncertain on account of *CN* band. |
| 3883.423 | Measured in spark between *Ag* electrodes. Blend *CN* in arc. |
| 3894.291 | Blend *Sa* II to red in arc. |
| 3933.583 | Blend *Ca* in arc. |
| 3960.501 | Blend faint *Sa* II in arc. |
| 4156.250 | Blend *CN* in furnace. |
| 4265.075 | Violet component faint. |
| 4295.741 | Blend *Ti* in furnace. |
| 4302.580 | Blend in arc with *Ca* impurity line. |
| 4313.338 | May be blend with *Sa* I. |
| 4336.775 | Coincident line in spark indicates blend *Sa* II. |
| 4426.011 | Blend *V* in furnace. |
| 4445.881 | Arc line partly *Sa* II? |
| 4522.546 | Arc line partly *Eu* II. |
| 4670.747 | Blend faint *Sa* II to violet. |
| 4682.689 | Blend *CN* in furnace. |
| 4688.11 | Faint *Sa* I on violet side. |
| 4691.89 | Shaded to red. |
| 4770 | λ 4770.29 is most persistent of pair at low temperature. |
| 4778.63 | Faint *Sa* II to red |
| 5359.3 | Furnace line may be *C*. |
| 5387.89<br>5388.03 | Unresolved doublet in arc measured λ 5387.97. |
| 5419.47 | Red component stronger. |
| 5420.51 | Violet component of arc doublet. Red component *Sa* II. |
| 5427.61 | Blend *Sa* II to violet in arc. |
| 5470.29 | Furnace line double. Red component faint in arc. |
| 5488.93 | Double in arc. Violet component *Sa* II. |
| 5492.50 | Blend faint *Sa* II in arc. |
| 5498.49 | Blend in arc with λ 5498.21. |
| 5509.35 | Red component stronger. |
| 5516.09 | Red component stronger. |
| 5519.87 | Blend in arc with λ 5519.62. |
| 5537.18 | Blend in arc with λ 5537.07. |
| 5550.11 | Blend in arc with λ 5550.40. |
| 5581.83 | Arc line probably blend *Sa* II to red. |
| 5583.25 | Red component stronger. |
| 5589.86 | Violet component faint. |
| 5604.70 | Blend *Sa* II to red in arc. |
| 5622.01 | Blend in arc with λ 5621.79. |
| 5637.30 | Blend faint *Sa* I to violet. |
| 5658.16 | Blend *Sa* II to violet in arc. |
| 5679.98 | Faint *Sa* II to violet in arc. |
| 5686.84 | Blend λ 5686.98. Partly *Sa* II in arc. |
| 5719.16 | Close blend *Sa* II in arc. |
| 5721.38 | Violet component *Sa* II. |
| 5727.04 | Blend *V* in furnace. |
| 5730.13 | Violet component *Sa* II. |
| 5741.19 | Arc line partly *Sa* II. |
| 5748.09 | Blend faint *Sa* I to violet. |
| 5774.02 | Blend in arc with λ 5773.77. |
| 5786.98 | Blend complex *Sa* I line in furnace. |
| 5788.38 | Blend faint *Sa* I to violet. |
| 5793.20 | Blend *Sa* II to red in arc. |
| 5814.89 | Blend in arc with faint *Sa* I to violet. |
| 5825.68 | Blend faint *Sa* II in arc. |
| 5851.02 | Blend *Sa* II to violet in arc. |
| 5858.15 | Faint *Sa* I to violet. |
| 5881.86 | Two faint *Sa* I lines to violet. |
| 5890.61 | Blend $D_2$ in arc. Faint *Sa* I line to violet. |
| 5895.35 | Blend $D_1$ in arc. |
| 5896.28 | Blend $D_2$ in arc. |
| 5896.55 | Blend $D_1$ in arc. |
| 5942.14 | Blend in arc with λ 5942.33. |
| 5965.52 | Blend in arc with λ 5965.71. |
| 6002.82 | Red component stronger. |
| 6009.89 | Faint *Sa* I line to violet. |

NOTES TO TABLE I—*Continued*

| λ | |
|---|---|
| 6038.52 | Center of blend of three *Sa* I lines. |
| 6045.39 | Close blend *Sa* II to violet in arc. |
| 6053.88 | Blend faint *Sa* I to violet. |
| 6068.27 | Faint *Sa* I to violet. |
| 6101.96 | Blend *Sa* II to violet in arc. |
| 6103.37 | Blend *Sa* II to violet in arc. |
| 6110.66 | λ for *Sa* I line. Blend in arc. |
| 6143.09 | Blend *Sa* I to red in arc. |
| 6159.56 | Blend *Sa* II to violet in arc. |
| 6179.88 | Blend *Sa* II to violet in arc. |
| 6191.23 | Close blend *Sa* II in arc. |
| 6192.64 | Blend *Sa* II to violet in arc. |
| 6217.17 | Faint *Sa* II to violet in arc. |
| 6220.89 | Blend *Sa* II to violet in arc. |
| 6225.48 | Blend *Sa* II to red in arc. |
| 6251.73 | Blend *V* in furnace. |
| 6256.54 | Blend in arc with λ 6256.66. |
| 6264.32 | Blend wide *Sa* II to violet in arc. |
| 6271.53 | Blend in arc with λ 6271.38. |
| 6302.40 | Furnace line probably *Sa* I. |
| 6307.06 | Faint *Sa* I line to violet. |
| 6314.57 | Faint *Sa* I line to red. |
| 6337.92 | Red component stronger. |
| 6340.10 | Blend *Sa* II to violet in arc. Furnace line doublet. |
| 6353.54 | Blend *Sa* II to violet in arc. |
| 6357.18 | Blend *Sa* II to red in arc. |
| 6377.27 | Blend *Sa* II to red in arc. |
| 6398.48 | Blend in arc with λ 6398.29. |
| 6401.45 | Blend *Sa* II to violet in arc. |
| 6403.98 | Blend *Sa* II to violet in arc. |
| 6426.64 | Arc line chiefly *Sa* II. |
| 6435.34 | Blend faint *Sa* I to red. |
| 6447.56 | Arc line partly *Sa* II. |
| 6472.19 | Blend in arc with λ 6472.34. |
| 6505.45 | Blend *Sa* II to red in arc. |
| 6509.44 | Blend band head in arc. |
| 6544.57 | Keiss λ. Blend in arc with λλ 6544.52, 6544.66. |
| 6591.50 | Blend *Sa* II in arc. Furnace line double. |
| 6671.51 | Blend faint *Sa* I to red. |
| 6693.55 | May be blend faint *Sa* I. |
| 6741.47 | Blend of strong doublet with fainter *Sa* II to violet |
| 6837.20 | Blend *Sa* I with wide *Sa* II in arc. |
| 6846.85 | Blend in arc with λ 6846.54. |
| 6848.16 | Double. |
| 6848.31 | Double. |
| 6852.94 | Blend double *Sa* II in arc. |
| 6872.64 | Blend in arc with λ 6872.43. |
| 6873.12 | Blend in arc with λ 6873.26. |
| 6875.33 | Blend in arc with λ 6875.27. |
| 6885.16 | Blend faint *Sa* I. |
| 6918.78<br>6919.03 | λ's for furnace doublet. Arc line partly *Sa* II. |
| 6952.39 | Blend in arc with double *Sa* II to red. |
| 6955.63 | Arc line chiefly *Sa* II. Furnace line narrow. |
| 6957.73 | Blend *Sa* II to red in arc. |
| 7000.76 | Close blend *Sa* II in arc. |
| 7020.22 | Blend in arc with λ 7020.44. |
| 7060.02 | May be *Ba*. |
| 7074.41 | Blend in arc with λ 7074.67. |
| 7120.05 | Blend in arc with λ 7119.81. |
| 7122.6 | Blend in arc with λ 7122.40. |
| 7124.86 | Blend in arc with λ 7124.50. |
| 7218.28 | Blend in arc with λ 7218.09. |
| 7264.4 | Blend of doublet with single line to violet. |
| 7412.24 | Center of wide blend, probably four lines. |
| 7662.94 | Blend in arc with potassium line. |
| 7755.32 | Measured in furnace. Blend in arc with λ 7655.20. |
| 7787.02 | Wide in arc. May be blend *Sa* II to red. |
| 7889.33 | Blend *CN* in furnace. |
| 7926.27 | Disturbed by *CN* in furnace. |
| 7968.32 | Blend *CN* in furnace. |
| 8021.54 | Blend *CN* in furnace. |
| 8040.27 | Blend *CN* in furnace. |
| 8091.15 | Concealed by band in furnace. |
| 8102.38 | Blend *CN* in furnace. |
| 8122.29 | Furnace line may belong to band. |
| 8132.01 | Blend *CN* in furnace. |
| 8135.27 | Blend *CN* in furnace. |
| 8256.5 | Blend *CN* in furnace. |
| 8298.46 | Blend *CN* in furnace. |
| 8325.38 | Blend *CN* in furnace. |
| 8383.71 | Blend *Sa* II to violet in arc. |
| 8390.30 | Blend *Sa* II to violet in arc. |
| 8706.32 | Sharper than neighboring lines. Probably *Sa* I. |

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# SOME NOTES ON THE STRUCTURE OF ELLIPTICAL NEBULAE*

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ABSTRACT

The results of some observations of Messier 32, together with the known facts concerning this nebula, form the basis for a discussion of the structure of elliptical nebulae in general.

The following data are derived from the observations: (1) Within 75″ of the nucleus the light from M 32 shows no detectable polarization. (2) The existence of a definite nucleus is established, and its diameter is found to be $0''.8 \pm 0''.1$. (3) The spectral type, as determined from small-scale plates, shows no variation along the major axis of the nebula.

A discussion of three possible models for the elliptical nebulae, the gas-sphere or starlike model, the assembly of small particles suggested by ten Bruggencate, and the star-cluster model, indicates that the star-cluster model best accounts for the known facts. On the basis of this theory, assuming that the bulk of the stars are dG3, the total number of stars in M 32 is found to be $1.9 \times 10^7$ and the central density $8.8 \times 10^5$ stars/parsec$^3$. This extraordinarily high central density is, however, not thought to be a serious objection to the theory.

It is becoming increasingly evident that a group of cosmological questions must remain open until we arrive at a reasonably secure understanding of the elliptical nebulae. Within our present knowledge these objects may represent either a large part or a negligibly small fraction of the mass of the universe. If they are assemblages of dwarf stars, the very low luminosity per gram of the dwarfs, as compared to that of the high-luminosity stars of the spirals, would imply that a large portion of the mass of the universe may be concentrated in these nebulae. If, on the other hand, they consist of "super" luminous bodies surrounded by a dust cloud, they may have totally insignificant masses.

Data on the velocities of individual nebulae in clusters are accumulating to a point where the total mass within the cluster can be estimated; but how shall we distribute this mass? Since most of the nebulae in clusters are elliptical, shall we say that they make up the main mass of the cluster, or must we postulate a large quantity of internebular material in the clusters? Or again, if we consider observations on individual elliptical nebulae, will dynamics serve, or

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must we call on hydrodynamics for our interpretations? In the one case such observations on rotation as those of Pease may yield a value of the mass; in the other, the mass may be indeterminate.

From Hubble's researches we know something of the distances and general dimensions of the elliptical nebulae, but their detailed structure is still an open question. An investigation now in progress has yielded some new data. The observations deal with Messier 32, selected for detailed study because it is bright, accessible, and typical of its class. Polarization of the light from the outer regions, the size of the nucleus, and the character of the spectrum in regions well away from the nucleus were investigated and are now discussed in the following paragraphs.

## POLARIZATION

If the light from the extra-nuclear regions of elliptical nebulae were found to show radial polarization, we should have strong evidence that these regions contain non-luminous material which only scatters the light originating in the nucleus. J. H. Reynolds[1] reported finding an indication of such an effect, but later investigations have failed to substantiate his results.[2] The experiments described here have also failed to find any trace of polarized light.

The first attempt to detect polarization was made visually with the kind help of Dr. F. E. Wright. At the request of the writer, Dr. Wright tried his very sensitive polarizing eyepiece[3] at the Newtonian focus of the 100-inch telescope, but the light intensity in the outer regions of M 32 proved to be insufficient for measurement by this method.

A second attempt was made photographically with a large quartz Wollaston prism. Since reflection from silver mirrors at 45° incidence is known to produce polarization, the Newtonian flat was removed and the Wollaston prism mounted in the tube at the primary focus of the 100-inch mirror. A short-focus negative lens placed in front of the prism rendered the light from the telescope parallel, and a short-focus positive lens following the prism brought the light

[1] *M.N.*, **72**, 553, 1911.

[2] W. K. Green, *Pub. A.S.P.*, **29**, 108, 1917; W. F. Meyer, *ibid.*, **31**, 194, 1919.

[3] *J. Opt. Soc. Amer.*, **24**, 206, 1934.

to a focus on a photographic plate. This combination produced double images, the light forming one of the images being polarized in a plane perpendicular to the plane of polarization of the light forming the second image. The whole assembly, consisting of prism, lenses, and plate-holder, was mounted as a unit and provided with a guiding eyepiece, focusing screw, and the usual accessories.

Messier 32 was photographed through this device, which was so oriented that the planes of polarization of the two images coincided with the principal axes of the nebula. Three photographs of the nebula were made on Imperial Eclipse plates with exposures of 30, 90, and 300 seconds, respectively.

Since the planes of polarization are mutually perpendicular, the light from the outer regions of the nebula, if partially polarized radially, should produce in the two images curves of constant intensity which differ in shape. Owing to the coincidence of the planes of polarization with the principal axes of the images, the isophotal curves approximate ellipses. Hence, the presence of radial polarization should show as a difference in the ratio of the axes of these isophotal ellipses in the two images. No such effect was found. From a study of microphotometer tracings of the images, it seems clear that, if polarization is present, it amounts to less than 2 per cent for points within 75″ of the nucleus. In regions more than 75″ from the nucleus, variations in the background fog make it difficult to set limits, but even here there is no suggestion of polarization.

The amount of polarization to be expected, if we assume the particles to be large compared to atoms, is probably that of moonlight when the moon is in quarter-phase. This quantity, according to B. Lyot,[4] is $7\frac{1}{2}$ per cent, which is well above our uncertainty. Mercury at quarter-phase gives a similar value. It might be argued that the polarization of the nebular light is reduced by multiple scattering; but the transparency of the outer regions of the nebula, as shown by the apparent sharpness of the nucleus, seems to rule out this notion.

### THE ANGULAR DIAMETER OF THE NUCLEUS

The appearance of Messier 32 when viewed in a large telescope, as well as its photographic image, suggests a central condensation or

[4] *C.R.*, **191**, 703, 1930.

nucleus, bounded either by a definite break or else by a very rapid change in the luminosity-density gradient. That such is indeed the case is shown by magnitude determinations of the nucleus treated as a star.[5] These measurements show that the nucleus is far more luminous than would be expected from Hubble's relation for luminosity distribution, which was derived from a study of the extranuclear regions. Hence we conclude that the luminosity distribution is discontinuous and that a nucleus exists which can be treated as a separate entity.

Examination of short-exposure photographs of M 32 indicated that no valid determination of the diameter of the nucleus could be made by direct photography. Exposures of 1–5 seconds with the 100-inch telescope show a somewhat starlike image having a slightly diffuse boundary. Since the size of the image is not very different from that of a star, much of its apparent size must be attributed to "seeing." Direct photography can therefore furnish only an upper limit for the diameter of the nucleus. On the best plates this seems to be from 1″.5 to 2″.

A lower limit was set with the aid of the 100-inch reflector converted into an interferometer. A 27-inch strip was mounted across the center of the tube, leaving as clear aperture two segments; this arrangement is equivalent to the usual form of stellar interferometer having a base of approximately 55 inches and a resolving power of 0″.1. That is, a star having an angular diameter of less than 0″.1 should show interference fringes. In the case of an object as faint as the nucleus of M 32, fringes would probably have to be well up on the visability-curve to be seen; hence the appearance of fringes would probably indicate a diameter of less than, say, 0″.08.

M 32, however, showed no interference fringes. A search was made on two nights, on the second of which observing conditions were excellent. The visibility of fringes was checked throughout the observing period by frequent observations of two nearby stars, one of about magnitude 10, the other of about the same brightness as the nucleus. The test stars served a further useful purpose by indicating the proper choice of eyepiece power, an item which becomes important in the case of faint objects. For this work 60× was found

[5] From some unpublished magnitudes by Dr. Hubble and Dr. Baade. See p. 199.

best. During the best observing period, about an hour while M 32 was crossing the meridian, fringes were continuously visible on the two test stars, but none appeared on M 32. Since fringes were not observed, one concludes that the nucleus has a diameter greater than 0".08.

At intervals during the search for fringes, micrometer eyepiece comparisons were made of the "image" of the nucleus with that of a nearby star. The measurements cannot be exact, for the illuminated area as seen under high magnification changes continuously both in shape and size. Even under the best atmospheric conditions "images" with the full aperture of the large reflectors are large compared to the theoretical diffraction disk. During the best period of these observations the stellar image had an average diameter of 0".5 instead of the theoretical 0".05. During the same interval a number of measures on the nucleus gave an average diameter of 1".1. In order to vary the illumination as much as possible, these comparisons were repeated with a series of eyepieces ranging from 100× to 600 ×. Since the same value was derived in each case, it is assumed that these measures give the apparent diameter of the nucleus under the given conditions of seeing.

The precise interpretation of these eyepiece measurements presents some difficulty, but they do yield an approximate value for the nuclear diameter. Certainly the measured value, 1".1, is an upper limit. A lower limit can be set by assuming that inhomogeneities in the atmosphere produce the same increase in the apparent size of the nucleus as in a star. Since the apparent diameter of the star is 0".5 instead of the theoretical 0".05, we can subtract the difference between these two quantities from the measured 1".1 and thus obtain a lower limit of 0".65. The true value is probably not much larger than this limit and is tentatively assumed to be 0".8 ± 0".1.

## SPECTRA

Spectroscopic observations of M 32 have been confined to a series of plates taken along the major axis at different distances from the nucleus. These spectra were compared with each other and with that of the nucleus, both visually and with the aid of a microphotometer. No differences were observed, either in spectral type

as determined by the spectral lines or in spectral distribution as measured with the microphotometer. Small changes, however, would undoubtedly have been missed, since all the spectra were taken with short-focus cameras. Spectrograms of larger dispersion are much to be desired, but they involve hopelessly long exposure times. A series consisting of the nucleus and points 12″, 16″, and 34″ north of the nucleus and 12″ and 16″ south was taken with a two-prism spectrograph having an $f/0.6$ Rayton camera. A few additional plates were taken with a quartz instrument fitted with an $f/1.0$ Schmidt camera. All plates agreed in showing no difference in spectrum in different parts of the nebula. Moreover, there seems to be no change in spectral type over a considerable spectral range. Both the visible and the ultra-violet spectra are indistinguishable from those of a $dG_3$ star photographed with the same instrument; and in a recent contribution Öhman[6] reports that the red end of the spectrum also shows no change in type.

This constancy of apparent spectral type over the observed range in wave-length adds difficulty to the already difficult task of interpreting our observations. If the nebula consisted of an assemblage of stars spread over a considerable range in spectral type, we should expect the dominant spectral type to vary with the spectral region in which it was observed. Failure to observe the effect does not, however, rule out the assemblage of stars as a model; it merely sets limits on the distribution function of spectral type.

## DISCUSSION

The significance of these results for the problem of the constitution of the elliptical nebulae must be discussed in terms of the various models that have been suggested. Three cases appear sufficient, since all the hypotheses concerning the structure of these objects fall into one of three groups.

### THE GAS-SPHERE MODEL

Consider first the gas-sphere or starlike model supported by Jeans. On dynamical grounds Jeans concludes that the observed forms of elliptical nebulae indicate the existence of a hydrostatic

[6] *Mt. W. Contr.*, No. 498; *Ap. J.*, **80**, 171, 1934.

pressure which can exist only if the nebulae are composed of very small particles. He states:

> . . . . if the nebulae were pure clouds of stars, they would have no clearly defined structure or features, but would extend indefinitely into space in the way in which the globular clusters are observed to do and the galactic system is believed to do. To restrain the nebulae to their observed definite shapes, the concept of a gaseous free path is necessary.[7]

Actually, the elliptical nebulae do extend indefinitely into space. For example, Hubble[8] says: "As far as observation can be pushed the diameters [of elliptical nebulae] increase with the exposure." Thus it appears that Jeans's criterion does not apply to elliptical nebulae.

Further objections to the gas-sphere model appear when we consider the spectroscopic observations. Such a sphere should certainly show an emission spectrum in the extra-nuclear regions, but no such spectrum is found. An even more serious difficulty appears when we consider the origin of the spectrum actually observed. Such a spectrum must be produced in some layer in the gas sphere in which conditions approximate, at least in order of magnitude, those in the photosphere of a $dG_3$ star. From the observed luminosity one can determine the area of the emitting surface; and, as will be shown in a later paragraph, this area turns out to be equal to the surface area of $1.9 \times 10^7$ $dG_3$ stars. A reasonable estimate of the distance of M 32 indicates that such a spherical shell as seen from the earth should have an angular diameter of $10^{-5}$ seconds of arc instead of the very much larger measured diameter.

### TEN BRUGGENCATE'S MODEL

P. ten Bruggencate[9] pictures an elliptical nebula as a highly luminous nucleus surrounded by a mass of non-luminous particles. From the observed projected luminosity distribution he derives an expression for the space distribution of luminosity, which is approximately the inverse-square law. Since this hypothesis supposes the luminosity at any point in the nebula to be proportional to the

[7] Jeans, *Astronomy and Cosmogony* (2d ed.; Cambridge, 1929), p. 344.

[8] For a full discussion of rotation see Jeans, *op. cit.*, chap. vii.

[9] *Zs. f. Ap.*, 1, 275, 1930.

illumination multiplied by the scattering (i.e., presumably the density) at that point, and since the illumination follows the inverse-square law, one concludes that the density of particles along any radius is approximately constant. This would mean that in a nebula having a ratio of axes of 3:10, which, according to ten Bruggencate, is the most frequent ratio, the density, although remaining constant along every radius, would, along the major axis, be $(10/3)^2$, or about ten times as great as along the minor axis. As far as this writer can determine, no dynamical system of any degree of stability could yield such a density distribution.

A further objection to this model arises from the fact that the light from the extra-nuclear regions should be polarized; whereas no polarization has thus far been detected.

### THE STAR-CLUSTER MODEL

This model pictures an elliptical nebula as a very large globular star cluster. In the case of M 32, since the spectrum is dG3,[10] it is assumed that the cluster consists mainly of stars of this class. With the help of Hubble's luminosity-distribution relation,[11] his absolute magnitude, the measured diameter of the nucleus, and the apparent magnitudes of the whole nebula and of the nucleus alone,[12] it is possible to construct a reasonably complete model of this object. The following values are used for the various quantities:

| | |
|---|---|
| 1. Absolute magnitude (vis.) | −13.2 |
| 2. Distance | 275,000 parsecs |
| 3. Magnitude of nucleus (pg.) | 13.4 |
| 4. Total magnitude of nebula (pg.) | 9.6 |
| 5. Diameter of nucleus | 0".8 |
| 6. Mean absolute magnitude of individual stars | 5.0 |

From (1) and (6) we find for the total number of stars in the nebula $1.9 \times 10^7$.

From (3) and (4) we find that 3 per cent of all the stars are in the nucleus as projected on the sky. This value for the nucleus, of course, includes stars in the extra-nuclear region that are in line of sight with

[10] Humason, *Mt. W. Contr.*, No. 426; *Ap. J.*, **74**, 35, 1931.

[11] *Mt. W. Contr.*, No. 398; *Ap. J.*, **71**, 231, 1930.

[12] These values were very kindly furnished by Dr. Hubble and Dr. Baade.

the nucleus; but by integrating Hubble's luminosity function over the nuclear region and comparing the result with the value of the integral for the whole nebula, we find that these line-of-sight stars can be neglected.[13] Hence, $0.03\times10^7$ or $5.7\times10^5$ stars must be assigned to the nucleus.

For the adopted distance of 275,000 parsecs, the nuclear density becomes $8.8\times10^5$ stars/parsec$^3$. Although this density is much higher than that of any known part of our galaxy, the stars must not be thought of as crowded. Their average separation would be about 0.01 parsec, which gives a mean free path large compared to the nucleus. The velocity of escape from the boundary of such a region is 95 km/sec., and an observer within such a region would see as his closest neighbors about a dozen stars of magnitude $-5$. At about 0.5 parsecs from the center of the system the density begins to fall off rapidly; continuing at a less rapid rate, it reaches the value of approximately 1 star per 10 cubic parsecs at our arbitrary boundary of 250 parsecs from the center.

This model seems the least objectionable of the three. The extraordinarily high central density cannot be pressed as an objection, for one must expect to find the nuclei of elliptical nebulae very different from more familiar regions of space. Perhaps the strongest argument for this hypothesis arises from a consideration of the area of emitting surface necessary to account for the luminosity of the nucleus. In the discussion of the gas-sphere model it was pointed out that this radiation must have its origin in a region in which conditions are approximately the same as in the photosphere of a

[13] The total luminosity within a radius $R$ is given by

$$L_R=\int_0^R \frac{I_0 2\pi r a^2}{(r+a)^2}\,dr=2\pi a^2\left[\log(r+a)+\frac{a}{r+a}\right]_0^R,$$

where $I_0$ and $a$ are constants determined from observation in the extra-nuclear regions. For M 32 they are 228 and 3.1, respectively, and $r$ is in units of $2''.03$. Since $L_\infty=\infty$, we must stop at some large value of $R$, say $R=90r=183''$.

Hence the ratio of $L_{\text{nucleus}}$ to total luminosity becomes

$$\frac{L_{0''.4}}{L_{183''}}=10^{-3}.$$

$dG_3$ star and that the radiating surface must equal that of some $5.7 \times 10^5$ $dG_3$ stars. It is unlikely that any single structure could meet these requirements. It seems far more likely that the $dG_3$ radiation is produced by $dG_3$ stars.

Since no positive demonstration of the validity of any model is immediately available, theory must for the moment remain very insecure. Nevertheless, the outlook is not hopeless, for it will be evident from the foregoing discussion that much remains to be done on the problem before we need be discouraged about its ultimate solution.

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# THE RADIAL VELOCITIES OF THE STARS OF SPECTRAL CLASSES R AND N*

By ROSCOE F. SANFORD

ABSTRACT

*The catalogue.*—An attempt is made to bring together in Table I all the radial velocities of the stars whose spectra show the bands of carbon. Those of class N have been reduced to a velocity system which harmonizes laboratory and stellar data.

*Velocities from emission lines.*—Twenty stars of class N having emission lines of hydrogen give −21.6 km/sec. for the mean difference between the radial velocities depending upon them and those from the absorption features. These stars are all variable with a mean period of 407 days and a mean range of 4 mag. Emission lines of hydrogen are usually associated with stars having a large magnitude range, and in such stars as fail to show them the explanation may be that the observations occur at the wrong phase, since the intensity of emission is known to fall to zero at certain phases. Moreover, the presence of emission in the spectrum of a star not known to vary should cause it to be suspected of variability.

*Solar motion, galactic rotation, and absolute magnitude.*—A least-squares solution based upon all the material for the class-N stars gives a solar motion quite similar to that for the naked-eye stars, a galactic rotation term of 13.4 km/sec., a mean distance of 0.727 kiloparsecs, a mean absolute magnitude of −1.4, and 315° as the longitude of the galactic center.

The reality of the galactic rotation term is strengthened by dividing the stars into three groups, whose mean apparent magnitudes are 6.5, 8.1, and 9.3, and solving these groups for galactic rotation alone after the elimination of the solar motion. The three results are 7.2, 16.3, and 22.4 km/sec.—a quite consistently progressive increase.

Mean absolute magnitudes for the three groups are computed on the basis of their mean apparent magnitudes and mean distances. These latter can be obtained from the constant for the increase of the galactic-rotation term per kiloparsec as obtained from the investigations of stars of class B and of Cepheid variables. Using the constant obtained by Joy for the latter stars, the values of the absolute magnitude are −1.4, −1.5, and −1.1, respectively. The constant for the B stars gives absolute magnitudes 0.4 brighter.

Heretofore the radial velocities of stars of spectral classes R and N were to be found only in the following lists: 8 N stars by Hale, Ellerman, and Parkhurst,[1] 10 R stars by W. C. Rufus,[2] 25 of class N by J. H. Moore,[3] and 30 of class R by R. F. Sanford.[4]

Immediately following the completion of the last list a program for the radial velocities of stars of class N was started by the writer

* *Contributions from the Mount Wilson Observatory, Carnegie Institution of Washington*, No. 525.

[1] *Pub. Yerkes Obs.*, **2**, 341, 1903.

[2] *Pub. Detroit Obs.*, **2**, 135, 1916.

[3] *Lick Obs. Bull.*, **10**, 160–168, 1922.

[4] *Mt. W. Contr.*, No. 276; *Ap. J.*, **59**, 339, 1924.

with the idea of increasing as far as possible the number obtained by Moore, an increase which would have been rather moderate if both the plates available and the spectrographic equipment had not in the meantime undergone marked improvement. With only a few exceptions, the spectrograms used in this investigation were obtained with the stellar plane-grating spectrograph designed by Merrill and described[5] by him in *Mount Wilson Contribution* No. 432. Suitable spectrograms of stars of spectral class N as faint as visual magnitude $8\frac{1}{2}$ may under good conditions be obtained in the red with exposures of the order of two hours by using ammoniated Eastman 3C plates.

It thus became possible to photograph even more than had been anticipated of the stars of class N from the *Henry Draper Catalogue*. In addition, a considerable number of spectrograms was obtained for the purpose of checking the classification of discoveries[6] of this spectral class upon objective-prism spectra photographed at Mount Wilson with the 10-inch telescope. Most of these latter stars were of the ninth visual magnitude or fainter and necessitated the use of a short-focus camera with a resultant dispersion of 110 A per millimeter. Some of the other faint stars were also photographed in this manner. Otherwise, for the most part, a camera of 10-inch focus, with a dispersion of 65 A per millimeter, was employed. A dispersion of 33 A per millimeter was obtained by using an 18-inch camera for a few stars. Some exposures of exceptionally high dispersion were made with various coudé spectrographs. Such a spectrogram of Y Canum Venaticorum made with a concave-grating spectrograph has a dispersion of approximately 3.5 A per millimeter.

In the spectra of stars of this class, the identification of the complex absorption features has never been entirely satisfactory. The Swann, cyanogen, and hydrocarbon bands and certain very conspicuous lines such as those of sodium are well known. But a large percentage of the details, notably those extending into the visual region which Shane[7] measured, remained unidentified.

At first, therefore, it was decided to use Moore's results as a basis for the velocities of standards for the Hartmann spectrocomparator

[5] *Ap. J.*, **74**, 188–200, 1931.

[6] *Pub. A.S.P.*, **45**, 306–308, 1933.

[7] *Lick Obs. Bull.*, **10**, 79–92, 1920.

and for the wave-lengths to be used for micrometer measurement—a practice followed until a large number of spectrograms had been obtained with the grating spectrograph. During this time these wave-lengths were improved, and some features adopted at first were rejected as not being generally useful.

The region measured on the grating spectrograms includes the D lines, which, when suitably exposed, offered an opportunity of comparison with the wave-length system employed. Twenty-one spectrograms were selected, each of which furnished a good determination of the radial velocity, both from the D lines, by using solar wave-lengths, and from other tabular features. The differences were remarkably consistent and significantly large, the sodium lines giving algebraically smaller radial velocities. Further checks seemed desirable.

A good opportunity was offered when Merrill[8] found that in the far red the spectra of stars of class N could be largely accounted for by the details of the cyanogen band spectrum, and when, at his suggestion, I looked for and found the same to be true in the red region.

An intercomparison of spectra of class-N stars and King's furnace spectra resulted in the identification of many features for which accurate wave-lengths could be measured on the laboratory spectrograms. A new set of wave-lengths was thus obtained which included the features already used. Radial velocities were then computed on the basis of the old tabular wave-lengths as well as on that of the new wave-lengths of these same features and also on the basis of the additional features measured. The three comparisons are given below together with their mean:

| | |
|---|---|
| D lines—old tables | −5 km/sec. |
| Revised λλ—old λλ (same features) | 8 |
| New lines—old lines (old λλ) | −0 |
| Mean | −7 |

Hence velocities based upon the old tables need to be decreased by 7 km to conform to the new system.

This correction is significantly like the K term which Moore obtained from his solution for the solar motion. He was of course well

[8] *Mt. W. Contr.*, No. 486; *Ap. J.*, **79**, 202, 1933.

aware of the fact that this K term would have largely disappeared had he not applied a systematic correction to the velocities from low-dispersion spectrograms. He concluded to use this correction, however, since its necessity was indicated by such intercomparisons as were possible, although he was frank to point out some of their unavoidable deficiencies. His radial velocities, corrected by −7 km/sec., may be compared with the writer's in twenty-one cases. Since three of these intercomparisons involve low weight in one case or the other, eighteen well-determined values remain common to both lists. The mean of their differences is practically zero.

It may also be remarked that the mean of the differences between the velocities of the eight class-N stars given by Hale, Ellerman, and Parkhurst and their velocities determined at Mount Wilson is −4 km/sec.

Table I includes all the velocities of stars of class N obtained at Mount Wilson; of those few below our declination limit obtained by the D. O. Mills expedition, at Santiago, Chile, and appearing in Moore's list; and of some miscellaneous stars originally suspected of belonging to this spectral class. The velocities of stars of spectral Class R as given in *Contribution* No. 276[4] are included, together with a few observed later. Table I should therefore contain a complete list of the known radial velocities of stars in whose spectra the bands of carbon appear.

The class-N stars from the *Henry Draper Catalogue* within reach of Mount Wilson and not yet observed for radial velocity are as follows: HD 44653, 46321, 47396, 48664, 52225, 57160, 57884, 58195, 58385, 60952, 172804, 190606, 191783, 195665. To these should be added three stars from the Mount Wilson list,[6] Nos. 26, 27, and 32. Practically all have visual apparent magnitudes 9 or fainter.

Among the class-R stars there remain likewise the following from the *Henry Draper Catalogue:* HD 27108, 63130, 70138, 78278, 163838, 166097, 166129, 170282, 171399, 179355, 187216, 188934, 215673, 216649, 218851. No magnitudes are given for six of these, while the mean apparent visual magnitude for the remainder is 10.4, which accounts for the lack of observations.

The *Henry Draper Catalogue* has, in large part, furnished its number, the BD designation, the co-ordinates for 1900, the magnitudes, and the types for Table I. Additional information on the mag-

## TABLE I*

### RADIAL VELOCITIES OF STARS OF CLASSES N AND R

| | HD No. | Designation | 1900 | | Magnitude | | Type | Vel. Km/Sec. | | Galactic | | Notes | Period |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $\alpha$ | $\delta$ | Max. | Min. | | Abs. | Em. | $l$ | $b$ | | |
| | | | | | | | | | | | | | days |
| 1 | 1306 | ST Cas | $0^h12^m2$ | $+49°44'$ | 7.5 | 9.0 | Nb | − 43 | ..... | 85° | −12° | (33) | ..... |
| 2 | 1546 | VX And | 14.6 | +44 9 | 8.1 | 9.5 | NcN7 | + 8 *a* | ..... | 85 | −18 | (27) | ..... |
| 3 | 1994 | BD+53°66 | 19.1 | +53 44 | 9.7 | ..... | R5R5 | − 36 *c* | ..... | 86 | − 8 | (1) | ..... |
| 4 | 2342 | AQ And | 22.2 | +35 2 | 7.8 | 8.0 | Nb | − 7 *d* | ..... | 86 | −27 | ..... | ..... |
| 5 | 5223 | BD+23°123 | 48.9 | +23 32 | 8.8 | ..... | R3 | −234 *b* | ..... | 91 | −32 | (1) | ..... |
| 6 | 7561 | Z Psc | 1 10.6 | +25 14 | 7.4 | 8.1 | NaNo | + 22 *b* | ..... | 98 | −36 | (20) | ..... |
| 7 | 8879 | R Scl | 22.4 | −33 4 | 6.2 | 8.8 | Np | − 8 *c* | ..... | 211 | −80 | (20).. | 376 |
| 8 | ..... | WW Cas | 27.1 | +57 14 | 9.1 | 11.7 | (N1) | − 58 *e* | ..... | 96 | − 4 | (2)(32) | ..... |
| 9 | 10636 | BD+53°379 | 38.7 | +53 28 | 9.9 | ..... | R5 | − 33 *e* | ..... | 99 | − 8 | ..... | ..... |
| 10 | ..... | X Cas | 49.8 | +58 46 | 8.4 | 13.1 | (N1e) | − 57 *c* | −80 | 99 | − 1 | ..... | 425 |
| 11 | 13826 | V Ari | 2 9.6 | +11 47 | 8.3 | 9.0 | NbR8 | −183 *b* | ..... | 122 | −44 | (21) | ..... |
| 12 | ..... | MSB 2 | 20.1 | +51 37 | ..... | ..... | (N3) | − 54 *e* | ..... | 105 | − 8 | (2) | ..... |
| 13 | 16115 | BD−10°513 | 30.2 | − 9 53 | 8.3 | ..... | R3R3 | + 11 *b* | ..... | 150 | −58 | (1) | ..... |
| 14 | 16326 | UY And | 32.1 | +38 44 | *11.0* | *14.0* | N | − 58 *e* | ..... | 113 | −18 | ..... | ..... |
| 15 | 19557 | BD+57°702 | 3 3.7 | +57 31 | 8.1 | ..... | R5R5 | − 6 *a* | ..... | 108 | 0 | (1) | ..... |
| 16 | 19881 | BD+47°783 | 6.7 | +47 27 | 9.2 | ..... | Np | + 10 *e* | ..... | 114 | − 8 | ..... | ..... |
| 17 | 20234 | CD−57°513 | 10.0 | −57 41 | 5.7 | ..... | Na | + 14 | ..... | 240 | −50 | (3) | ..... |
| 18 | 21280 | Y Per | 20.9 | +43 50 | 8.3 | 11.0 | Nbe | − 4 *c* | −14 | 118 | − 9 | ..... | 254 |
| 19 | 22611 | U Cam | 33.2 | +62 19 | 6.9 | 9.0 | NbN5 | − 3 *c* | ..... | 109 | + 7 | ..... | 419 |
| 20 | ..... | BD+51°762 | 33.9 | +51 2 | 8.9 | ..... | (N2) | + 6 *c* | ..... | 115 | − 2 | (2) | ..... |
| 21 | ..... | AC Per | 38.1 | +44 28 | *10.2* | *12.3* | (N3) | − 33 *e* | ..... | 120 | − 7 | (2)(20) | ..... |
| 22 | ..... | MSB 5 | 41.5 | +52 54 | ..... | ..... | S | − 82 *e* | ..... | 115 | 0 | (2)(34) | ..... |

* The small letters following the velocities represent the possible uncertainties in each from the writer's estimates based upon a consideration of the probable errors, the number of spectrograms, and their quality and dispersion. They may be interpreted as follows: (*a*) Three or more spectrograms; uncertainty of 1 km/sec. possible. (*b*) Three or more spectrograms; uncertainty of 2–3 km/sec. possible. (*c*) Only two spectrograms; uncertainty of 1–3 km/sec. indicated. (*d*) Only two spectrograms; uncertainty of 3–5 km/sec. indicated. (*e*) All cases in which the probable error exceeds 5 km/sec. and those in which the velocity depends on a single spectrogram.

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 23 | 25408 | BD+61°667 | 3h57m2 | +61°32′ | 7.9 | ..... | R8R8 | − 10 *b* | ..... | 111° | + 8° | (1) | ..... |
| 24 | ..... | SY Per | 4 8.9 | +50 23 | 9.5 | 12.5 | ($N_3$) | 0 *e* | ..... | 120 | 1 | (2)(25) | 476 |
| 25 | ..... | MSB 7 | 13.0 | +40 53 | ..... | ..... | ($N_3$) | − 2 *e* | ..... | 128 | − 5 | (2) | ..... |
| 26 | ..... | MSB 8 | 22.9 | +39 38 | ..... | ..... | (N1) | + 13 *e* | ..... | 129 | − 5 | (2) | ..... |
| 27 | ..... | AV Per | 32.6 | +41 26 | *13.5* | *15.0* | (N1) | + 41 *e* | ..... | 130 | − 2 | (2) | ..... |
| 28 | 30243 | ST Cam | 40.8 | +67 59 | 7.0 | 8.3 | Nb | − 23 *e* | ..... | 110 | +16 | ..... | ..... |
| 29 | 30443 | BD+34°911 | 42.7 | +34 49 | 9.0 | ..... | Nb | + 76 *e* | ..... | 136 | − 5 | ..... | ..... |
| 30 | 30533 | T Cae | 43.8 | −36 23 | *8.7* | *10.3* | Nb | − 7 | ..... | 205 | −39 | (31) | ..... |
| 31 | 30710 | BD+15°691 | 44.9 | +15 37 | 10.1 | ..... | Na | + 38 *c* | ..... | 151 | −16 | ..... | ..... |
| 32 | 30755 | TT Tau | 45.2 | +28 21 | 8.1 | 8.8 | $NbN_3$ | + 20 *c* | ..... | 142 | − 9 | ..... | 166 |
| 33 | ..... | BD+38°955 | 45.7 | +38 20 | 8.8 | ..... | (No) | + 24 *c* | ..... | 133 | − 2 | (2)(20) | ..... |
| 34 | ..... | MSB 11 | 46.8 | +49 46 | ..... | ..... | (Noe) | + 4 *c* | − 22 | 125 | + 5 | (2)(30) | ..... |
| 35 | 31996 | R Lep | 55.0 | −14 57 | 6.1 | 9.7 | PecN6e | + 32 | − 1 | 182 | −31 | (5)(21) | 440 |
| 36 | 32088 | BD+50°1112 | 55.6 | +50 29 | 9.0 | ..... | Nb | − 12 *e* | ..... | 125 | 7 | ..... | ..... |
| 37 | 32736 | W Ori | 5 0.2 | + 1 2 | 5.9 | 7.7 | $NbN_5$ | + 16 *a* | ..... | 167 | −21 | ..... | 200 |
| 38 | 33016 | TX Aur | 2.2 | +38 52 | 8.5 | 9.2 | Nb | − 6 *c* | ..... | 135 | + 1 | ..... | 330? |
| 39 | 33404 | BD−5°1174 | 4.9 | − 5 38 | 8.6 | ..... | NbNo | + 23 *e* | ..... | 173 | −24 | (32) | ..... |
| 40 | 34467 | BD+35°1046 | 12.5 | +35 41 | 9.1 | ..... | Nb | − 2 *e* | ..... | 139 | + 1 | (32) | ..... |
| 41 | 34842 | UV Aur | 15.3 | +32 24 | 7.9 | 10.1 | Se | ..... | − 15 | 142 | − 1 | (11) | 350 |
| 42 | 35556 | S Aur | 20.5 | +34 4 | 9.3 | 12 | Nb | + 3 *d* | ..... | 141 | + 1 | (25) | 591 |
| 43 | 36602 | RT Ori | 27.8 | + 7 4 | 7.5 | 8.5 | Nb | + 5 *c* | ..... | 165 | −12 | ..... | ..... |
| 44 | 36972 | S Cam | 30.2 | +68 45 | 7.8 | 10.8 | R8eNp | − 13 *e* | − 17 | 111 | +20 | ..... | 311 |
| 45 | 37212 | CD−25°2539 | 31.7 | −25 48 | 7.9 | ..... | Na | + 40 *b* | ..... | 197 | −26 | ..... | ..... |
| 46 | 38218 | TU Tau | 39.1 | +24 23 | 8.7 | 9.5 | $NbN_2$ | − 24 *c* | ..... | 152 | − 1 | (35) | ..... |
| 47 | 38307 | Y Tau | 39.7 | +20 39 | 6.9 | 8.9 | $NbN_2$ | − 17 *c* | ..... | 155 | − 3 | ..... | 240 |
| 48 | ..... | BD+15°921 | 39.7 | +15 28 | 9.5 | ..... | (No) | + 22 *e* | ..... | 159 | − 5 | (2) | ..... |
| 49 | 38521 | AF Aur | 41.4 | +44 50 | 8.5 | 9.5 | Pec | − 11 *e* | ..... | 134 | +10 | (2) | ..... |
| 50 | 38572 | BD+30°1014 | 41.7 | +30 36 | 9.0 | 9.3 | NaNo | + 18 *e* | ..... | 147 | + 2 | (20)(32) | ..... |
| 51 | ..... | Mayall's Var. | 54.2 | +39 42 | ..... | ..... | (Noe) | + 80 *a* | + 69 | 140 | +10 | (2)(20)(28) | 416 |
| 52 | 42272 | TU Gem | 6 4.7 | +26 3 | 7.4 | 8.3 | $NaN_3$ | + 48 *c* | ..... | 153 | + 5 | (20) | ..... |
| 53 | ..... | BD−0°1246 | 12.7 | − 0 12 | 9.5 | ..... | (No) | + 34 *e* | ..... | 177 | − 6 | (2) | ..... |
| 54 | ..... | MSB 17 | 13.4 | − 1 7 | ..... | ..... | ($N_3$) | + 80 *e* | ..... | 179 | − 7 | (2) | ..... |
| 55 | 44388 | V Aur | 16.5 | +47 45 | 8.3 | <12.2 | Nbe | + 6 *e* | + 3 | 134 | +17 | ..... | 357 |
| 56 | ..... | MSB 18 | 16.5 | + 7 21 | ..... | ..... | ($N_2$) | + 28 *e* | ..... | 171 | − 2 | (2) | ..... |
| 57 | ..... | BD−7°1402 | 18.5 | − 7 25 | 9.5 | ..... | (N) | + 46 *e* | ..... | 184 | − 8 | (2)(23) | ..... |

TABLE I—*Continued*

| | HD No. | Designation | 1900 | | Magnitude | | Type | Vel. Km/Sec. | | Galactic | | Notes | Period |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $\alpha$ | $\delta$ | Max. | Min. | | Abs. | Em. | $l$ | $b$ | | |
| | | | | | | | | | | | | | days |
| 58 | 44984 | BL Ori | $6^h19^m.8$ | $+14°48'$ | 6.6 | ..... | Nb | + 13 *c* | ..... | 164° | + 2° | 74 Schj | ..... |
| 59 | 45087 | AB Gem | 20.3 | +19 8 | ..... | ..... | ($N_3$) | + 7 *d* | ..... | 161 | + 5 | (2) | ..... |
| 60 | ..... | CD−26°2983 | 20.5 | −27 1 | 8.6 | ..... | N | + 23 *e* | ..... | 202 | −16 | (2) | ..... |
| 61 | ..... | BD+12°1177 | 25.3 | +12 33 | 9.4 | ..... | ($N_2$) | − 14 *e* | ..... | 167 | + 3 | (2) | ..... |
| 62 | 46687 | UU Aur | 29.7 | +38 31 | 6.2 | 6.7 | $NaN_3$ | + 11 *a* | ..... | 144 | +15 | 78 Schj | ..... |
| 63 | 47883 | VW Gem | 35.7 | +31 33 | 8.6 | 8.8 | Na | + 14 *c* | ..... | 151 | +14 | ..... | ..... |
| 64 | 50436 | BD−4°1708 | 48.2 | − 4 27 | *9.2* | *10.4* | Nb | + 38 *d* | ..... | 185 | 0 | ..... | ..... |
| 65 | 50949 | UW Aur | 50.3 | +41 14 | *9.6* | *12.6* | ($N_3$) | 0 *e* | ..... | 143 | +20 | ..... | 530 |
| 66 | 51208 | CD−42°2818 | 51.3 | −42 14 | 6.0 | ..... | Na | + 32 *e* | ..... | 219 | −17 | (20) | ..... |
| 67 | ..... | BD+6°1451 | 51.7 | + 6 29 | 9.5 | ..... | ($N_3$) | + 57 *e* | ..... | 176 | + 6 | (2) | ..... |
| 68 | 51620 | RV Mon | 53.0 | + 6 18 | 7.0 | 8.2 | Nb | + 16 *b* | ..... | 176 | + 6 | ..... | ..... |
| 69 | 52432 | BD−3°1685 | 56.1 | − 3 6 | 7.5 | ..... | $R_5$ | + 24 *c* | ..... | 185 | + 2 | (1)(12) | ..... |
| 70 | ..... | RY Mon | 7 2.1 | − 7 24 | 7.7 | 9.1 | ($N_5$) | + 2 *c* | ..... | 189 | + 1 | (2) | ..... |
| 71 | 54361 | W CMa | 3.4 | −11 46 | 6.9 | 7.5 | Na | + 21 *d* | ..... | 193 | − 1 | ..... | ..... |
| 72 | 55284 | V Gem | 7.2 | +14 46 | *10.8* | *14.9* | Rpe | + 53 *d* | + 42 | 171 | +12 | (1)(13) | ..... |
| 73 | ..... | BD+5°1606 | 10.3 | + 5 14 | 9.5 | ..... | ($N_3$) | + 56 *e* | ..... | 179 | + 9 | (2)(23) | ..... |
| 74 | 56167 | RU Cam | 10.9 | +69 52 | 7.9 | 9.0 | KoRo | − 24 | ..... | 118 | +29 | (6) | 22.17 |
| 75 | 58337 | BD+22°1679 | 20.1 | +22 7 | 10.0 | ..... | $R_5R_3$ | + 4 *e* | ..... | 164 | +18 | ..... | ..... |
| 76 | 58364 | BD+22°1680 | 20.2 | +22 5 | 9.8 | ..... | $R_5R_3$ | − 3 *c* | ..... | 164 | +18 | ..... | ..... |
| 77 | 59643 | BD+24°1684 | 25.8 | +24 44 | 8.2 | ..... | R8R9 | + 43 *e* | ..... | 161 | +18 | (1) | ..... |
| 78 | 60826 | BD+2°1715 | 31.3 | + 2 18 | 8.7 | 9.1 | Na | + 40 *e* | ..... | 184 | +13 | ..... | ..... |
| 79 | 63353 | W CMi | 43.4 | + 5 40 | *9.8* | *11.3* | R8 | + 25 *e* | ..... | 182 | +17 | ..... | ..... |
| 80 | ..... | MSB 31 | 45.0 | − 0 38 | ..... | ..... | ($N_3$) | 0 *e* | ..... | 189 | +14 | (2)(18) | ..... |
| 81 | ..... | MSB 33 | 57.5 | − 1 51 | ..... | ..... | (N6) | + 26 *e* | ..... | 191 | +16 | (2) | ..... |
| 82 | 67190 | RT Pup | 8 1.7 | −38 29 | *9.3* | *10.2* | Nb | + 28 *d* | ..... | 222 | − 3 | ..... | ..... |
| 83 | 67507 | RU Pup | 3.2 | −22 37 | *9.4* | *11.6* | Nb | + 23 *e* | ..... | 210 | + 6 | ..... | ..... |
| 84 | 70072 | RY Hya | 14.9 | + 3 5 | 8.3 | 9.6 | Nbe | + 17 *c* | − 8 | 189 | +22 | (23) | 535 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 85 | ..... | T Lyn | $8^h16^m.4$ | +33°50′ | 8.0 | 12.0 | (Noe) | + 5 *c* | − 9 | 156° | +34° | (20) | 416 |
| 86 | 75021 | CD−29°6735 | 42.4 | −29 21 | 7.6 | ..... | R8R7 | + 13 *b* | ..... | 220 | + 9 | (1) | ..... |
| 87 | 76221 | X Can | 49.7 | +17 37 | 6.1 | 6.6 | NbN3 | − 2 *c* | ..... | 178 | +37 | 115 Schj | 130 |
| 88 | 76396 | BD+51°1462 | 50.8 | +51 49 | 8.8 | ..... | R5 | − 52 *e* | ..... | 134 | +41 | ..... | ..... |
| 89 | ..... | T Can | 51.0 | +20 14 | 8.0 | 10.2 | NN3 | + 4 *c* | ..... | 175 | +37 | (23) | 500 |
| 90 | 76846 | BD+34°1929 | 53.6 | +34 9 | 9.2 | ..... | Ro | + 26 *e* | ..... | 157 | +42 | (1) | ..... |
| 91 | 77234 | BD+50°1603 | 56.2 | +50 29 | 9.5 | ..... | R5R5 | + 5 *a* | ..... | 135 | +43 | (1) | ..... |
| 92 | 79319 | BD+14°2048 | 9 8.3 | +14 37 | 8.9 | ..... | R5R4 | + 1 *e* | ..... | 184 | +39 | (1) | ..... |
| 93 | 85319 | W Sex | 45.9 | − 1 33 | 10.3 | 12.3 | Nbe | + 63 *c* | + 28 | 208 | +39 | ..... | ..... |
| 94 | 85405 | Y Hya | 46.4 | −22 32 | 6.5 | 8.0 | NpN3 | + 7 *c* | ..... | 226 | +24 | ..... | 80? |
| 95 | 86111 | X Vel | 51.3 | −41 7 | *9.5* | *11.8* | Nb | − 7 *e* | ..... | 239 | +11 | (31) | ..... |
| 96 | 88539 | CD−34°6528 | 10 7.5 | −34 50 | 7.0 | ..... | Na | + 4 *b* | ..... | 238 | +18 | ..... | ..... |
| 97 | 91793 | U Ant | 30.8 | −39 3 | *8.3* | *9.3* | Nb | + 37 *c* | ..... | 244 | +16 | ..... | 168? |
| 98 | 92055 | U Hya | 32.6 | −12 52 | 4.5 | 6.3 | NbN2 | − 27 *b* | ..... | 229 | +39 | 132 Schj | ..... |
| 99 | 92839 | BD+68°617 | 38.1 | +67 56 | 6.3 | ..... | Na | − 18 *e* | ..... | 106 | +46 | (14) | ..... |
| 100 | ..... | V Hya | 46.8 | −20 43 | 6.7 | 12.0 | (N6) | − 13 *b* | ..... | 237 | +35 | 318 Birm (20) | 527 |
| 101 | 95405 | ..... | 55.7 | −25 19 | 9.0 | ..... | Kp | + 12 *e* | ..... | 242 | +31 | (15) | ..... |
| 102 | 100764 | BD−13°3407 | 11 30.7 | −14 2 | 8.7 | ..... | Ro | + 5 *b* | ..... | 246 | +45 | (1) | ..... |
| 103 | 107957 | S Cen | 12 19.2 | −48 53 | *8.1* | *9.5* | Nbp | − 41 | ..... | 266 | +13 | (3) | ..... |
| 104 | 108105 | SS Vir | 20.1 | + 1 20 | 7.2 | 9.0 | PecNp | + 6 *c* | ..... | 259 | +63 | (36) | ..... |
| 105 | 108683 | CD−37°7905 | 24.0 | −37 42 | 9.3 | ..... | (No) | + 46 *e* | ..... | 266 | +24 | ..... | ..... |
| 106 | 110914 | Y CVn | 40.4 | +45 58 | 4.8 | 6.0 | NbN3 | + 12 *a* | ..... | 90 | +72 | 152 Schj | ..... |
| 107 | 111166 | RU Vir | 42.2 | + 4 42 | 8 | 12.6 | R3ep | − 1 *b* | − 18 | 271 | +66 | ..... | 439 |
| 108 | 112559 | RY Dra | 52.5 | +66 32 | 6.1 | 7.1 | N4p | − 20 *d* | ..... | 88 | +51 | ..... | ..... |
| 109 | 112869 | BD+38°2389 | 54.7 | +38 20 | 9.2 | 9.6 | NbR6p | −128 *d* | ..... | 74 | +79 | (23) | ..... |
| 110 | 113801 | BD−19°3634 | 13 1.1 | −19 31 | 8.7 | ..... | K5R | − 8 *e* | ..... | 276 | +42 | ..... | ..... |
| 111 | 128033 | Z Lup | 14 29.5 | −42 56 | *8.2* | *9.6* | Na | + 14 *c* | ..... | 290 | +15 | ..... | ..... |
| 112 | 133332 | BD−2°3939 | 58.8 | − 2 28 | 10.6 | ..... | R5 | − 28 *e* | ..... | 323 | +45 | (1) | ..... |
| 113 | 134453 | X TrA | 15 4.8 | −69 42 | *8.2* | *10.0* | Nb | − 4 *e* | ..... | 282 | −11 | (3) | ..... |
| 114 | 137613 | CD−24°12084 | 21.9 | −24 49 | 7.4 | ..... | RoR3 | + 57 *b* | ..... | 310 | +25 | (1)(23) | ..... |
| 115 | 141826 | V CrB | 45.9 | +39 52 | 7.2 | 12.0 | Nb2 | −115 *e* | −139 | 30 | +50 | ..... | 357 |
| 116 | 144578 | RR Her | 16 1.5 | +50 46 | 7.8 | 9.5 | K5ep | − 46 *e* | − 39 | 46 | +46 | (8) | 242 |
| 117 | 145777 | BD−14°4371 | 7.6 | −14 57 | 10.7 | ..... | Ro | + 18 *e* | ..... | 326 | +24 | (1) | ..... |
| 118 | 148173 | CD−43°10810 | 21.1 | −43 27 | 9.3 | ..... | N | + 5 *e* | ..... | 306 | + 2 | ..... | ..... |

TABLE I—*Continued*

| | HD No. | Designation | 1900 | | Magnitude | | Type | Vel. Km/Sec. | | Galactic | | Notes | Period |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $\alpha$ | $\delta$ | Max. | Min. | | Abs. | Em. | $l$ | $b$ | | |
| | | | | | | | | | | | | | days |
| 119 | 148182 | V Oph | $16^h21^m.2$ | $-12°12'$ | 7.0 | 10.5 | Nb | $-48\,d$ | $-68$ | 331° | $+23°$ | ..... | 301 |
| 120 | ..... | SU Sco | 34.2 | $-32\ 11$ | 7.5 | 9.0 | No | $-19\,c$ | ..... | 317 | $+8$ | ..... | ..... |
| 121 | 156074 | BD$+42°2811$ | 17 10.4 | $+42\ 15$ | 7.7 | ..... | RoR | $-11\,b$ | ..... | 37 | $+34$ | (1)(16) | ..... |
| 122 | ..... | CD$-39°11452$ | 20.7 | $-39\ 55$ | ..... | ..... | ($N_3$) | $-30\,e$ | ..... | 316 | $-4$ | (2) | ..... |
| 123 | 158377 | TW Oph | 23.8 | $-19\ 24$ | 7.8 | ..... | Nb | $+14\,c$ | ..... | 334 | $+7$ | ..... | ..... |
| 124 | 160205 | TT Sco | 33.5 | $-41\ 35$ | *9.0* | *11.2* | ($N_3$) | $+10\,e$ | ..... | 316 | $-7$ | ..... | ..... |
| 125 | 160591 | CD$-35°11829$ | 35.7 | $-35\ 12$ | *10.7* | *11.6* | Nb | $-57\,e$ | ..... | 322 | $-4$ | ..... | ..... |
| 126 | 161208 | SZ Sgr | 39.1 | $-18\ 37$ | *8.5* | *9.8* | Nb | $+17\,e$ | ..... | 336 | $+4$ | (20) | ..... |
| 127 | 161511 | SX Sco | 40.8 | $-35\ 39$ | *9.6* | *11.1* | Nb | $-49\,e$ | ..... | 322 | $-6$ | ..... | 128? |
| 128 | ..... | T Dra | 54.9 | $+58\ 14$ | 7.5 | 14.0 | Noe | $-12\,e$ | $-38$ | 53 | $+29$ | ..... | 425 |
| 129 | 168227 | BD$-15°4923$ | 18 13.6 | $-15\ 39$ | 9.0 | 9.8 | $R_5$ | $-19\,c$ | ..... | 344 | $-2$ | (1) | ..... |
| 130 | 170495 | SS Sgr | 24.6 | $-16\ 59$ | *11.0* | *12.0* | Nb | $0\,c$ | ..... | 343 | $-4$ | ..... | ..... |
| 131 | 170831 | TY Oph | 26.4 | $+4\ 19$ | *9* | *10* | Nb | $-27\,e$ | ..... | 2 | $+5$ | ..... | ..... |
| 132 | ..... | T Lyr | 28.9 | $+36\ 54$ | 7.8 | 9.6 | ($N_3$) | $-21\,e$ | ..... | 33 | $+18$ | ..... | ..... |
| 133 | 171804 | RX Sct | 31.7 | $-7\ 41$ | *9.7* | *12.0* | Nb | $-2\,d$ | ..... | 352 | $-2$ | ..... | ..... |
| 134 | 173291 | BD$+36°3243$ | 39.4 | $+36\ 51$ | 8.1 | ..... | Nb | $-6\,e$ | ..... | 33 | $+17$ | ..... | ..... |
| 135 | 173409 | CD$-31°15954$ | 40.0 | $-31\ 28$ | 9.2 | ..... | Ro | $-65\,e$ | ..... | 331 | $-14$ | (1) | ..... |
| 136 | 174325 | S Sct | 44.9 | $-8\ 1$ | 6.4 | 7.3 | $NbN_3$ | $-2\,b$ | ..... | 354 | $-5$ | ..... | 144 |
| 137 | 175377 | T Sct | 50.0 | $-8\ 19$ | 8.8 | 9.3 | $NbN_3$ | $+26\,c$ | ..... | 354 | $-6$ | ..... | ..... |
| 138 | 175893 | CD$-29°15574$ | 52.4 | $-29\ 38$ | 9.3 | ..... | $R_1$ | $+42\,c$ | ..... | 335 | $-16$ | (1) | ..... |
| 139 | 176200 | UV Aql | 54.0 | $+14\ 14$ | *9.6* | *11.6* | $NbN_4$ | $+21\,b$ | ..... | 14 | $+4$ | ..... | ..... |
| 140 | 177336 | V Aql | 59.1 | $-5\ 50$ | 6.5 | 8.0 | $NpN_6$ | $+36\,c$ | ..... | 357 | $-7$ | ..... | ..... |
| 141 | 178316 | BD$-17°5492$ | 19 3.0 | $-17\ 26$ | 10.6 | ..... | $RoR_4$ | $-45\,e$ | ..... | 347 | $-13$ | (1) | ..... |
| 142 | 179153 | ..... | 6.3 | $-1\ 33$ | *10.8* | *11.7* | Nb | $+30\,e$ | ..... | 2 | $-6$ | ..... | ..... |
| 143 | 180953 | ..... | 13.4 | $-16\ 5$ | 7.2 | ..... | $NaN_2$ | $-46\,d$ | ..... | 349 | $-15$ | ..... | ..... |
| 144 | ..... | U Lyr | 16.7 | $+37\ 37$ | 8.3 | 12.0 | (Noe) | $-2\,c$ | $-36$ | 37 | $+10$ | (2) | 460 |
| 145 | 182040 | BD$-10°5057$ | 17.7 | $-10\ 53$ | 7.0 | ..... | RoRo | $-49\,a$ | ..... | 354 | $-13$ | (1) | ..... |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 146 | 183556 | UX Dra | 19h25m1 | +76°23′ | 6.1 | 7.1 | NbNo | + 7 *d* | ..... | 75° | +24° | ..... | ..... |
| 147 | ..... | AW Cyg | 25.8 | +45 50 | 8.0 | 10.2 | ($N_3$) | − 12 *c* | ..... | 46 | +12 | (2) | ..... |
| 148 | 184283 | AQ Sgr | 28.6 | −16 35 | *8.5* | *9.7* | $NbN_3$ | + 20 *e* | ..... | 351 | −18 | (20) | ..... |
| 149 | 186047 | TT Cyg | 37.1 | +32 23 | 7.3 | 8.4 | Nb | − 49 *b* | ..... | 35 | + 4 | ..... | 120 |
| 150 | 186665 | UW Sgr | 40.6 | −18 24 | *8.4* | *10.2* | Na | + 1 *e* | ..... | 350 | −22 | ..... | ..... |
| 151 | 188934 | BD−0°3883 | 52.5 | − 0 2 | 9.8 | ..... | $R_3R8$ | + 56 *c* | ..... | 9 | −16 | (1) | ..... |
| 152 | 189256 | AX Cyg | 54.0 | +43 59 | 7.4 | 7.9 | Nb | − 4 *b* | ..... | 47 | + 7 | ..... | ..... |
| 153 | 189605 | BD−7°5141 | 55.7 | − 7 39 | 10.8 | ..... | Nb | + 41 *e* | ..... | 2 | −20 | ..... | ..... |
| 154 | 189711 | BD+9°4369 | 56.3 | + 9 14 | 8.7 | ..... | Nb | −164 *e* | ..... | 17 | −12 | ..... | ..... |
| 155 | ..... | MSB 37 | 58.6 | +30 23 | ..... | ..... | ($N_3$) | + 8 *e* | ..... | 36 | − 1 | (2) | ..... |
| 156 | 191738 | SV Cyg | 20 6.4 | +47 33 | 8.1 | 9.4 | $NbN_3$ | − 8 *c* | ..... | 52 | + 8 | ..... | ..... |
| 157 | 192443 | RS Cyg | 9.8 | +38 26 | 7.5 | 8.7 | NapNope | − 46 *e* | − 55 | 43 | + 2 | (20) | ..... |
| 158 | 192737 | RT Cap | 11.3 | −21 38 | *8.6* | *10.4* | Nb | − 30 *e* | ..... | 350 | −29 | ..... | ..... |
| 159 | 193368 | WX Cyg | 14.8 | +37 9 | 9.0 | 12.2 | Nbe | + 38 *c* | + 2 | 43 | 0 | ..... | 410 |
| 160 | 193650 | U Cyg | 16.5 | +47 35 | 6.1 | 11.8 | R9Npe | + 10 | + 3 | 52 | + 6 | (9)(20)(22) | 453 |
| 161 | 195435 | BD−12°5755 | 26.2 | −12 13 | 9.6 | ..... | $R_5$ | − 52 *c* | ..... | 1 | −29 | (1) | ..... |
| 162 | 195665 | AD Cyg | 27.6 | +32 14 | *8.5* | *9.5* | S | − 1 *e* | ..... | 41 | − 5 | (17) | 73? |
| 163 | ..... | MSB 38 | 33.9 | +59 44 | ..... | ..... | ($N_3$) | − 43 *e* | ..... | 63 | +11 | (2) | ..... |
| 164 | ..... | V Cyg | 38.1 | +47 48 | 6.8 | 13.8 | Npe | + 3 *e* | − 44 | 54 | + 3 | (2) | 416 |
| 165 | ..... | BD+31°4201 | 39.4 | +31 46 | 9.2 | ..... | ($N_3$) | − 24 *e* | ..... | 42 | − 7 | (2) | ..... |
| 166 | 197604 | BD+34°4134 | 39.7 | +34 43 | 9.8 | ..... | $R_3$ | + 21 *c* | ..... | 44 | − 7 | (1) | ..... |
| 167 | 198140 | BD−19°5930 | 43.2 | −19 24 | 10.3 | ..... | Ro | + 46 *d* | ..... | 355 | −36 | (1) | ..... |
| 168 | ..... | BD+32°3954 | 45.2 | +32 51 | 9.2 | ..... | ($N_3$) | − 11 *e* | ..... | 44 | − 7 | (2)(18) | ..... |
| 169 | 198681 | ..... | 46.9 | +45 2 | ..... | ..... | Nb | − 7 *e* | ..... | 53 | 0 | ..... | ..... |
| 170 | 202874 | T Ind | 21 13.6 | −45 27 | *7.2* | *8.9* | Na | + 2 | ..... | 323 | −46 | (3) | ..... |
| 171 | 205777 | BD+60°2267 | 32.5 | +60 28 | 10.3 | ..... | ($N_3$) | − 19 *e* | ..... | 69 | + 6 | ..... | ..... |
| 172 | 206362 | S Cep | 36.4 | +78 10 | 7.9 | 13.1 | Nce | − 34 *b* | − 47 | 81 | +19 | ..... | 482 |
| 173 | 206570 | BD+34°4500 | 37.8 | +35 3 | 6.4 | ..... | $NbN_1$ | + 6 *b* | ..... | 53 | −14 | (20) | ..... |
| 174 | 206750 | RV Cyg | 39.1 | +37 34 | 7.1 | 9.3 | $NpN_5$ | − 1 *b* | ..... | 56 | −11 | ..... | ..... |
| 175 | 208512 | BD+49°3673 | 51.6 | +50 2 | 9.8 | ..... | Nc | − 12 *d* | ..... | 64 | − 4 | ..... | ..... |
| 176 | 208526 | RX Peg | 51.7 | +22 24 | 7.7 | 8.6 | $NbN_3$ | − 33 *b* | ..... | 47 | −25 | ..... | 175 |
| 177 | 209596 | ..... | 59.5 | +45 5 | ..... | ..... | Na | − 22 *e* | ..... | 63 | − 8 | (18) | ..... |
| 178 | 209621 | BD+20°5071 | 59.7 | +20 34 | 8.8 | ..... | $R_3R_3$ | −383 *b* | ..... | 47 | −27 | (1)(19) | ..... |
| 179 | 209890 | RZ Peg | 22 1.5 | +33 2 | *9.0* | *12.4* | Ne | − 46 *e* | − 61 | 56 | −18 | ..... | 440 |
| 180 | 215484 | BD+60°2432 | 40.4 | +61 12 | 9.0 | ..... | Nb | − 37 *e* | ..... | 76 | + 2 | ..... | ..... |

TABLE I—*Continued*

| | HD No. | Designation | 1900 | | Magnitude | | Type | Vel. Km/Sec. | | Galactic | | Notes | Period |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $\alpha$ | $\delta$ | Max. | Min. | | Abs. | Em. | $l$ | $b$ | | |
| | | | | | | | | | | | | | days |
| 181 | 216913 | BD+53°3033 | $22^h51^m.9$ | +53°41′ | 9.4 | ..... | Nb | − 14 *e* | ..... | 74° | − 5° | ..... | ..... |
| 182 | ..... | VY And | 57.3 | +45 21 | 9.5 | 11.0 | Nb | − 12 *e* | ..... | 72 | −13 | ..... | 149 |
| 183 | 218851 | BD−21°6376 | 23 6.3 | −21 32 | 9.4 | 10.8 | Ro | + 32 *c* | ..... | 11 | −68 | (1) | ..... |
| 184 | ..... | MSB 42 | 19.1 | +55 26 | ..... | ..... | ($N_3$) | − 34 *d* | ..... | 79 | − 4 | (2) | ..... |
| 185 | 220870 | BD+48°4051 | 22.2 | +48 58 | 9.7 | ..... | Nb | − 10 *e* | ..... | 77 | −11 | ..... | ..... |
| 186 | 222241 | ST And | 33.8 | +35 13 | 8.3 | 12.4 | Nb | + 32 *c* | + 13 | 75 | −25 | ..... | 338 |
| 187 | 223075 | 19 Psc | 41.3 | + 2 56 | 5.3 | ..... | NaNo | + 7 *a* | ..... | 63 | −56 | (10)(20) | ..... |
| 188 | 223392 | BD+5°5223 | 44.0 | + 5 50 | 8.8 | ..... | $R_3$ | − 22 *e* | ..... | 66 | −53 | (1) | ..... |
| 189 | 224855 | WZ Cas | 56.2 | +59 48 | 7.7 | ..... | NaN1p | − 36 *b* | ..... | 85 | − 2 | (20)280 Schj | ..... |
| 190 | 224959 | BD−3°5751 | 57.0 | − 3 23 | 9.9 | ..... | RoRo | −136 *e* | ..... | 63 | −64 | (1) | ..... |
| 191 | 225217 | SU And | 59.4 | +43 0 | 7.9 | 8.5 | Nb | − 6 | ..... | 82 | −18 | (24) | ..... |

NOTES TO TABLE I

(1) Taken from *Mt. W. Contr.*, No. 276, Table I.

(2) See Merrill, Sanford, and Burwell, *Pub. A.S.P.*, **45,** 306, 1933. When no other designation exists for one of these stars the number is given from this publication.

(3) Moore's velocity, in *Lick Obs. Bull.*, **10,** 160, 1922, corrected by −7 km/sec.

(4) Called to my attention by S. B. Nicholson, who noted its extreme redness on photographs of comet Nagata (1931*b*). Discovered independently by Miss Burwell and Merrill.

(5) Velocities range from +26 to +50 km/sec.

(6) Velocity-curve by Sanford, *Mt. W. Contr.*, No. 372; *Ap. J.*, **68,** 408, 1928.

(7) Velocity-range from +7.1 to +18.4 km/sec. Coudé plates range from +10.0 to +18.4 km/sec.

(8) Velocity from absorption lines for only one plate. Velocity from emission lines is the mean of several plates.

(9) Velocity range for absorption lines, +4 to +37 km/sec. Range for emission lines, −13 to +23 km/sec.

(10) Velocity range for absorption lines, 0 to +15 km/sec.

(11) Class S with sometimes (?) class N added. Has $10^m$ A-type companion.

(12) One grating plate gives +23 km/sec.

(13) May be class S.
(14) Overlooked in solution.
(15) May be class K5R.
(16) Additional plate gives −12 km/sec.
(17) This is of spectral class S.
(18) This star has a fainter companion.
(19) Mean of two later plates, −383 km/sec.
(20) Very strong D lines.
(21) Seems to be variation in strength of the D lines.
(22) Velocity probably variable. Range −11 to +39 km/sec.
(23) D lines very weak.
(24) The good plates give +15, −17, and −15 km/sec. Velocity variable?
(25) Doubtful evidence of weak bright *Hα* for this star.
(26) Velocity probably variable.
(27) Spectral classifications with numerical subscripts are those of Shane, *Lick Obs. Bull.*, **13**, 123, 1928, except those in parentheses, which are rough estimates by the writer based on Shane's system.
(28) General spectrum most nearly like that of 19 Piscium but much redder and D lines much more intense as, e.g., in R Leporis.
(29) Two better-exposed spectrograms give −167 and −167 km/sec. and seem also to have a pair of interstellar D lines with velocities of +1 and −5 km/sec.
(30) More recent data (Prager, "Katalog und Ephemeriden veränderlicher Sterne für 1935," *Kleinere Veröff. Universitätssternwarte Berlin-Babelsberg*, No. 14, 1934. Star 34 AV Aur $13^{m}.5$–$15^{m}$ph; 39 SY Eri $8^{m}.0$–$9^{m}.6$; 42 S Aur $8^{m}.3$–$12^{m}$; 51 AZ Aur $10^{m}.5$–$15^{m}.5$ ph; 169 DS Cyg $12^{m}.9$–$15^{m}.1$ ph; 175 LW Cyg $10^{m}.5$–$11^{m}.5$ ph; 181 TV Lac $11^{m}.7$–$12^{m}.7$ ph.
(31) Obtained after solution was made.
(32) More recent velocity determinations for the following stars are:

| No. | Vel. | No. | Vel. |
|---|---|---|---|
| 8..... | −50 km/sec. | 50..... | +20 km/sec. |
| 21..... | −31 | 57..... | 53 |
| 39..... | + 4 | 73..... | 48 |
| 40..... | +19 | 80..... | +10 |

(33) Velocity may be variable; range −35 to −55 km/sec.
(34) Velocity from D lines only.
(35) Composite spectrum; class Ao in the violet region. See Shane, *op. cit.*, p. 124.
(36) *Hα* appears as an emission line on a spectrogram covering the region λλ 6500–7600, March 19, 1935, but with no certainty on any of the earlier spectrograms.

nitudes and periods was obtained from Prager's catalogue[9] and from the Mount Wilson discoveries previously alluded to. Galactic coordinates were taken from the Lund tables[10] for the nearest $4^m$ in $\alpha$ and $1^\circ$ in $\delta$. The magnitudes for some of the class-N stars in the *Henry Draper Catalogue* and most of those in the Mount Wilson list are not known. These latter were not in the *Henry Draper Catalogue* either because of extreme redness or extreme faintness or because the Harvard observations occurred at unfavorable phases in a great magnitude variation. Magnitudes in italics are photographic; the remainder are visual. Spectral classifications with numerical subscripts are from Shane's work,[11] rough estimates on his system for such stars as have not been otherwise classified being placed in parentheses. Under "Abs." are given the velocities from the absorption features, while "Em." denotes velocities from the emission lines of hydrogen, generally $H\alpha$ alone.

*Velocities from the emission lines.*—Two lists of stars of classes N and R with emission lines of hydrogen have been previously published,[12] and all these are again included in Table I. In these two lists the means of the difference in velocity between emission (generally $H\alpha$) and absorption lines are $-27$ and $-25$ km/sec., respectively. These, however, involve a few stars of spectral class R and all the absorption-line velocities for N-type stars on the old uncorrected system. In all, twenty stars of spectral class N with emission lines of hydrogen are entered in Table I. The mean difference between their velocities from emission and absorption is $-21.6$ km/sec., a numerical decrease from the two previously published values, attributable mainly to the application of the systematic correction to the absorption velocities and slightly to additional observations and to the limitation to only stars of class N.

The mean period for the seventeen of these twenty stars for which data are available is 407 days. The velocity difference here found

[9] "Katalog und Ephemeriden veränderlicher Sterne in 1934," *Kleinere Veröff. Universitätssternwarte Berlin-Babelsberg*, No. 13, 1933.

[10] John Ohlsson, *Ann. Obs. Lund*, No. 3, 1932.

[11] *Op. cit.*, **13**, 123, 1928.

[12] *Pub. A.S.P.*, **42**, 287, 1930; **45**, 44, 1933.

lies between those predicted by Merrill's[13] curves for stars of classes Me and Se. There is a slight correlation with period, smaller differences being associated with shorter periods, but this correlation is too poor to be stressed. With one exception these stars are variable, with a mean range of 4 mag. For some of them there are several spectrograms, representing all phases pretty well, which show that the hydrogen lines may vary from intense emission to practical extinction. Counting from maximum, the emission lines in R Leporis and U Cygni, for example, fade to extinction during the first quarter-period, remain suppressed for another quarter-period or until about light-minimum, then gradually increase, attaining maximum strength during the third quarter-period, which intensity continues until light maximum. The failure to find emission lines in the case of a star with large magnitude range might be attributed to the phase at which it was observed, the star being therefore no exception to the rule. In fact, I have found no certain evidence of bright hydrogen lines for four stars in whose spectra they were noted by Shane.[7] These are RV Cygni, $7^m.1$–$9^m.3$; Y Tauri, $6^m.9$–$8^m.9$, period 233 days; U Camelopardalis, $6^m.9$–$9^m.0$, period 418 days; and V Aquilae, $6^m.5$–$8^m.0$.

It would seem, therefore, that emission lines accompany a large magnitude range, that their failure to be observed in case the range is large is not necessarily evidence that they are not present at the appropriate phases, and that their appearance in a star of class N not known to vary should arouse a suspicion of variability. MSB 11 $\alpha = 4^h46^m.8$, $\delta = +49°46'$ (1900), is an example of the last point.

*Solar motion, galactic rotation, and absolute magnitude from the radial velocities of stars of spectral class N.*—The recent success of Plaskett and Pearce[14] in finding evidence of galactic rotation, both from the radial velocities of the B-type stars and from their detached lines of calcium, and of A. H. Joy,[15] from the Cepheid variables, demands a similar treatment of whatever other data are available. Such an investigation evidently requires objects located at relatively large distances.

[13] *Mt. W. Contr.*, No. 264; *Ap. J.*, **58**, 251, Fig. 2, 1923.

[14] *Pub. Dom. Ap. Obs.*, **5**, 167–237, 1933.

[15] *Pub. A.S.P.*, **45**, 202, 1933.

Various investigators find values for the mean absolute magnitude of stars of spectral class N between the limits $-1.3$ and $-2.5$. Since their apparent magnitudes are in only a few cases brighter than 6 and in many cases fainter than 8, it is evident that N stars too are relatively distant objects and worthy of consideration in connection with the problem of galactic rotation. The 146 radial velocities of class-N stars in Table I are distributed among the different apparent visual magnitudes[16] roughly as follows:

| | |
|---|---|
| Brighter than 6 | 11 |
| 6.0–6.9 | 27 |
| 7.0–7.9 | 32 |
| 8.0–8.9 | 28 |
| 9.0 | 48 |

The velocities show a very considerable spread which has been smoothed out for the purpose of solution by forming two groups for each band of 30° of galactic longitude, in one of which the galactic latitudes are positive and in the other negative. Since some bands are deficient in stars with negative values of the galactic latitude, twenty groups resulted. All velocities were given equal weight in forming a normal, as it seemed more important that each group depend upon all the stars included in it than largely upon the few better observed stars. No velocity, however large, was omitted.

Except for the effect of random motion, each of these twenty mean velocities ($V$) was assumed to be conditioned as follows:

$$V = K + X \cos b \cos l + Y \cos b \sin l + Z \sin b + du + ev .$$

$l$ and $b$ are the galactic longitude and latitude. The first member on the right is the well-known $K$-term; $X$, $Y$, and Z are the components of the solar motion referred to galactic co-ordinates. Further,

$$u = \bar{r}A \cos 2l_0, \qquad d = \sin 2l \cos^2 b,$$
$$v = \bar{r}A \sin 2l_0, \qquad e = -\cos 2l \cos^2 b.$$

$A$ is the galactic rotation effect for a distance of 1 kiloparsec and $\bar{r}$ is the mean distance in kiloparsecs; $l_0$ denotes the longitude of the galactic center.

[16] A variable star was assigned its magnitude at maximum; a photographic magnitude was reduced to a visual magnitude by the mean color index +2.6; and some of the Mount Wilson discoveries for which magnitudes are not available have been arbitrarily assigned to the ninth magnitude.

A least-squares solution of the twenty normal equations was then carried through, weights being assigned to each roughly proportional to the number of stars involved. The results are given in Table II.

TABLE II

| | |
|---|---|
| $K = -\ 0.9 \pm 1.7$ km/sec. | $Z = -12.4 \pm 5.8$ km/sec. |
| $X = -18.6 \pm 2.2$ | $u = -\ 0.15 \pm 2.3$ |
| $Y = -\ 6.5 \pm 2.8$ | $v = -13.4 \pm 2.8$ |

The $K$-term is about one-half its probable error. The solar motion is 23.2 km/sec. toward the apex, whose right ascension is $17^h8^m$ and declination $+30°$, and thus agrees much better with that obtained from the naked-eye stars (20 km/sec. toward the apex with $\alpha = 18^h$ and $\delta = +30°$) than it does with Moore's[17] value (17.1 km/sec. toward the apex with $\alpha = 15^h$ and $\delta = +11°$) obtained from the radial velocities of only twenty-five bright class-N stars.

This solution gives the galactic rotation term ($\bar{r}A$) 13.4 km/sec. and the galactic center in the direction of $l_o = 315°$, for which Plaskett obtained 331° and Joy 324°. The latter's study of the Cepheid variables showed that galactic rotation increases by 18.5 km/sec. per kiloparsec from our stellar neighborhood, if absorption in space is allowed for. The mean distance in kiloparsecs may therefore be obtained, for the stars upon which it is based, by dividing the galactic rotation value ($\bar{r}A$) by 18.5. In this case the distance is 0.727 kiloparsecs, corresponding to an approximate mean parallax $\bar{\pi} = 0''.0014$. Although such a summary treatment of the data cannot give a rigorous value, it is of interest to note that the mean absolute magnitude from the foregoing value of $\bar{\pi}$ and the mean apparent magnitude, 7.9, is $-1.4$. Plaskett's value of $A$ ($=15.5$) gives $M = -1.8$. Wilson[18] obtained the approximate value $-1.4$ for the mean absolute magnitude, using the proper motions of ninety-two class-N stars and assuming Moore's value of the velocity of the solar motion. With the solar motion here obtained, his absolute magnitude would become $-2.1$. Other absolute magnitudes from proper motions are:

| No. of Stars | | |
|---|---|---|
| ? | $-1.3$ | Luplau-Janssen and Haarh* |
| 23 | 1.5 | Moore† |
| 120 | $-2.6$ | Kapteyn‡ |

* *A.N.*, **214**, 388, 1921. † *Lick Obs. Bull.*, **10**, 168, 1923. ‡ *Ap. J.*, **32**, 91, 1910.

[17] *Op. cit.*, p. 168.

[18] *A.J.*, **34**, 191, 1922.

Figure 1 shows how well the curve from this solution fits the twenty normal places reduced to $b=0$. The ordinates are radial velocities and the abscissae, galactic longitudes. Barred circles represent the normal places from stars with negative galactic latitudes, and open circles those from stars with positive ones, accompanying numbers indicating how many stars are involved in each normal place.

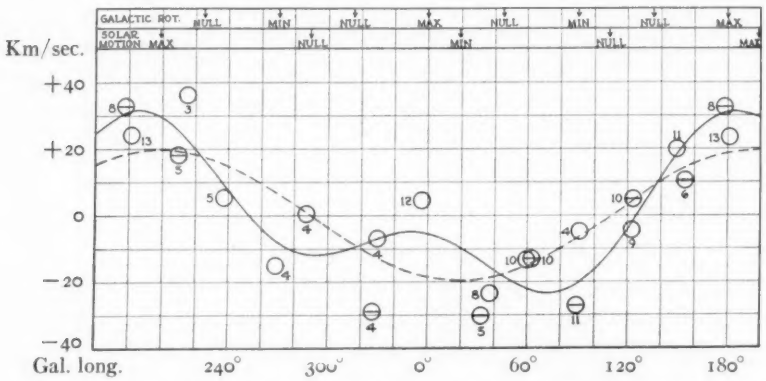


FIG. 1.—Solar motion and galactic rotation. Each circle represents a normal place, a bar indicating one derived from the velocities of stars in negative galactic latitudes. The number of velocities upon which a normal depends is given beside the circle. The full-line curve represents the combined solar motion and galactic rotation in the plane of the galaxy; the broken-line curve, the solar motion alone. Null, maximum, and minimum points for both galactic rotation and solar motion are given at the top of the figure.

It is frankly admitted that the scatter about the curve is considerable, which explains the large probable errors for the solution. It must be pointed out, however, that a representation of these normal places by solar motion alone would be quite unsatisfactory because the greater weight for the normals between galactic longitudes 70° and 180° would produce a sine-curve which would not at all represent the remaining galactic-longitude interval.

This solution is based upon class-N stars of all apparent magnitudes, but would be more convincing if the size of the galactic rotation term could be shown to depend upon mean apparent magnitude. To derive an approximate idea of this, the following procedure was adopted. It was first assumed that these stars give the ordinary solar apex with the solar motion velocity (23 km/sec.) here obtained,

and their individual velocities were corrected accordingly. Only stars with galactic latitudes between $+40^\circ$ and $-40^\circ$ were used, and one velocity exceeding $-100$ km/sec., which may in reality belong to spectral class R, was excluded. These were next divided into three groups according to apparent magnitude: the first, the stars brighter than 7.2; the second, those between this limit and 8.9; and a third group, the remainder, 9.0 or fainter. Finally, a least-squares solution was carried through for the stars in each group in which the residual velocity is represented by the conditional equation

$$\rho = \bar{r}A \sin 2(l-315^\circ) \cos^2 b .$$

TABLE III

| No. | $\bar{r}A$ Km/Sec. | $\bar{r}$ Kiloparsecs | | Mean Magnitude | | | $\bar{\rho}$ Km/Sec. |
|---|---|---|---|---|---|---|---|
| | | | | App. | Abs. | | |
| | | $A=18.5$ | $A=15.5$ | | $A=18.5$ | $A=15.5$ | |
| 41 | 7.2 | 0.390 | 0.465 | 6.5 | −1.4 | −1.8 | 17.3 |
| 48 | 16.3 | 0.879 | 1.050 | 8.2 | 1.5 | 1.9 | 21.6 |
| 44 | 22.4 | 1.211 | 1.445 | 9.3 | −1.1 | −1.5 | 22.1 |

Column 2, Table III,[19] gives the results of these solutions. The other columns contain, respectively: (1) the number of stars; (3) and (4) the mean distances obtained when Joy's $A$ and Plaskett's $A$ are assumed; (5) the mean apparent magnitudes; (6) and (7) the mean absolute magnitudes on the basis of the two values of $A$; and (8) the mean velocities freed from solar motion, sign being disregarded.

$\bar{r}A$ increases steadily with mean apparent magnitude; hence the reality of the rotation term from the general solution is greatly strengthened by the foregoing treatment. The spread in the derived absolute magnitudes is no more than might be expected from the probable errors, the uncertainties of the individual mean magnitudes

[19] The data in this table are to be preferred to those already given in *Pub. A.S.P.*, **46**, 228, 1934. The changes arise mainly from the use of the velocity from the solution for solar motion based on the N stars themselves; whereas the velocity derived from the naked-eye stars was used for the earlier results.

for the fainter stars, and the effect of space absorption. Moreover, any spread in the individual absolute magnitudes could result in a fainter mean absolute magnitude for the group of apparently faintest stars, since more of the absolutely fainter stars would conceivably enter such a group.

Although the absolute magnitudes of column 7 (using Plaskett's $A$) agree better with Wilson's mean absolute magnitude as revised, $-2.1$, the absolute magnitudes of column 6 are tentatively adopted; for Joy's $A$ upon which they depend is based upon not only the radial velocities of, but also the space absorption for, the Cepheid variables, the range of whose distances considerably exceeds those for the stars of class B. The weighted mean $M$ from column 6 is $-1.34$, in good agreement with the value $-1.4$ given earlier from all class-N stars.

The weighted mean of the peculiar motions without regard to sign ($\bar{\rho}$) is 20.4 km/sec., thus exceeding by 3.9 km/sec. the mean peculiar motion of class-M stars found by Campbell. Larger values, however, have been obtained by Merrill[20] for some subdivisions of spectral classes Me and Se.

*Double stars.*—The following class-N stars have companions:

| | | 1900 $\alpha$ | $\delta$ | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| HD 32218 | TU Tauri..... | $5^h39^m.1$ | $+24°23'$ | $8^m.7$–$9^m.5$ | Composite N2+Ao | | | | |
| | MSB 31..... | 7 45.0 | − 0 38 | | | | | | |
| βGC 10554 | BD+32°3954... | 20 45.2 | +32 51 | 9.2 | *AB* | pa | 243° | dist. | 10″.6 |
| | | | | | *AC* | pa | 140 | | 18.3 |
| | HD 209596.....21 | 59.5 | +45 5 | | | | | | |

| | $9^m.1$–$10^m.0$ |
|---|---|
| | |
| | 10.7 |

The components of the last three stars are widely separated, with the secondaries considerably fainter than the primaries. The first and third entries furnish some data about the absolute magnitudes of the class-N primaries. In the case of TU Tauri the secondary is estimated by Shane[21] to be a class-Ao star of apparent magnitude 11. The absolute visual magnitude of TU Tauri comes out $-1.8$ at maximum, if the most frequent absolute magnitude ($+0.5$) for type Ao, as given by Strömberg,[22] is assumed. A spectrogram of com-

[20] *Mt. W. Contr.*, No. 264; *Ap. J.*, **58**, 166, 1923.

[21] *Op. cit.*, **13**, 124, 1928.

[22] *Mt. W. Contr.*, No. 442; *Ap. J.*, **75**, 341, 1931.

ponent *B* of the third entry shows a class-G6 spectrum from which the absolute magnitude was estimated to be +0.1. On the assumption of physical connection, the derived absolute magnitude of *A* is −0.8. Its radial velocity is −11 km/sec. (low weight) and that of *B*, +8 km/sec. (depending on a single plate). Neither the magnitudes of the components nor the spectra of the secondaries are known in the other two cases. Such evidence as the first and third pairs furnish is in as good agreement with the results for absolute magnitude from the rotation effect as could be expected.

In conclusion, it seems appropriate to admit candidly the limitations in the accuracy of the velocities in Table I, which depend in a considerable degree upon few observations and often upon spectrograms of low dispersion. The velocities from spectrograms of low dispersion when compared with velocities obtained with higher dispersion have revealed no anomalies. Sufficient stars have been repeatedly observed to establish the fact that only a very few have velocity ranges which much exceed the accidental error to be expected. Hence it seemed best to concentrate upon securing approximate velocities for the greatest possible number of stars of class N rather than struggle for greater accuracy for a few stars. This assumes that the mean of a large number of approximate velocities better typifies the mean motion of a group of stars than does the mean of a few accurate velocities, some of which might represent abnormally large peculiar motions. Indeed, the final results would have differed very little from those actually obtained if the velocities from the first spectrogram of each star had been made the basis of the solutions.

CARNEGIE INSTITUTION OF WASHINGTON
MOUNT WILSON OBSERVATORY
April 1935

# REVIEWS

*A Finding List for Observers of Eclipsing Variables.* By RAYMOND SMITH DUGAN. ("Contributions from the Princeton University Observatory," No. 15 [1934].) Pp. 33.

Probably the most irksome task an observer has to perform is that of making out an observing program when the selection requires the consideration of data which must be extracted from widely scattered sources. One of the most unselfish acts an astronomer can perform is the collection and arrangement of data for a large class of objects in a form useful to others in selecting observing lists.

In his recent publication Professor Dugan gives in very concise form the most important data relating to 269 eclipsing systems. The list is not a catalogue of eclipsing binaries, nor is it simply a list of neglected objects. The stars included are all north of declination $-30°$ and mostly brighter than magnitude 13.0 at minimum. The list is not complete, even with these exceptions; one most important prerequisite for the inclusion of a star was that enough be known about it already to make the acquisition of further data very desirable and profitable. In the words of the author: "If there is already a good light curve or a good velocity curve this alone is enough to recommend the star for further observation."

The arrangement of stars is in order of right ascension, but a list by constellations enables one quickly to find a star by name. The information about each star is contained in a few lines of type on two facing pages, approximately twenty-five stars being listed on each pair of pages. The left-hand page is arranged in tabular form, giving approximate positions, periods, spectra, magnitudes at maxima, ranges of both minima, duration of eclipses, and extent of ellipsoidal variations. In a wide column headed "Points of Interest" several individual characteristics of nearly every star are given, especially those features which make further observation important. The numerous question marks in this column are a challenge to observers to furnish reliable information on doubtful points. Finally, the "direct exhortation to observers" is contained in the remaining columns. The types of observation which are especially urgent are indicated by asterisks (desirable) and exclamation points (very desirable) in the several columns whose headings indicate visual, photographic, photo-electric, radial velocity, and spectrographic observation, as well as determination of times of minima of stars whose periods are actually or possibly variable. The incomplete state of our knowledge of these stars is

indicated by the scarcity of a completely clear line across all six of these last columns.

On the right-hand page two or three lines of type refer to the most recent light-elements, light-curves, and orbit solutions. The names of observers now working on each star are given, and the method of observation is indicated. Observers will welcome especially the numerous warnings concerning variable comparison stars, as well as the listing of tested stars found to be constant in light. It would be difficult, indeed, to concentrate all this information into smaller compass. Numerous abbreviations are used, but most of them are so obvious that a key is almost superfluous. One can tell very quickly what stars can be profitably studied with his instrument and technique.

The explanation and general discussion which accompany the "Finding List" make more interesting reading than one might expect in a work of this nature. Attention is called to the value of a combined attack by all methods of observation, and to the importance of continued observations of times of minima of stars with variable periods. The discussion of methods of observation is thought-provoking, and probably many will disagree with the author on some points. It will be reassuring to many to find that an expert photometric observer has great respect for visual estimates. Among other things, the importance of eliminating Purkinje effect is pointed out.

Professor Dugan is to be congratulated on his success in arranging the "Finding List" in such form that an observer can select a program "rapidly, easily, and without exasperation." If it is used as it deserves to be, the author's hope "that the table, through the zeal of observers, will go quickly out of date" will be fulfilled.

DEAN B. MCLAUGHLIN

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*Fine Structure in Line Spectra and Nuclear Spin.* By S. TOLANSKY. London: Methuen & Co., 1935. Pp. viii+111. 3*s*.

This is a work on hyperfine structure, as will be evident from the last part of the title. The term "fine structure" is used throughout in place of "hyperfine structure." The terms "gross structure" and "multiplicity" are employed for the inner-quantum number multiplets. While everyone must welcome the elimination of the unsightly *hfs* abbreviation which is thus made certain, it remains questionable whether any single author should assume the responsibility for altering terms so deeply imbedded in the literature. It is also unfortunate that the author has prejudiced his claim to competency on such matters by the frequent use of the hasty slang current in informal discussions.

Leaving such matters out of consideration, the book can be unqualifiedly recommended as a simple yet authoritative account of the subject. Theoretical calculations are appropriately omitted, and an uncritical attitude is adopted toward their results, provided only that they are not in conflict with the data. The material is well chosen and well organized. Summaries are frequent and are italicized so that they are easily found. Each chapter is followed by a bibliography. About half of the book is devoted to an introduction which one unfamiliar with the subject will find necessary and understandable. The last half deals with the present status of the subject. The restriction of all considerations to the phenomena observed in line spectra is a real one, and the necessity of supplementing such data with others is emphasized. CARL ECKART

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*Elementary Quantum Mechanics.* By R. W. GURNEY. Cambridge: Cambridge University Press, 1934. Pp. 159+69 figs. $2.35.

To keep pace with modern developments, a physicist or chemist must learn to think in the new language of quantum theory. Dr. Gurney shows how this mental readjustment can be accomplished without detailed study of a new mathematical technique. The principles of quantum mechanics are presented "in a form congenial to the experimentalist," with potential energy curves and wave functions or "patterns" replacing the old dynamical models. From that it is not to be inferred that the treatment is entirely non-mathematical, but that physical interpretation has been stressed in every case, and exact derivations of formulae have, in general, been set apart in appendixes.

The range of topics covered is extensive, the only notable omission being the collision process, for which the reader is referred to the elementary treatment in Mott's *Outline of Wave Mechanics*. Complex spectra are passed over rather lightly in favor of diatomic molecules, valence bonds, and the theory of electronic conduction. The four or five pages devoted to the subject of insulators and conductors are particularly noteworthy, for they show how remarkably well the ideas of energy levels and the exclusion principle are adapted to a qualitative interpretation of conduction and its relation to optical properties. Such discussions should soon find their way into even the most elementary physics courses, bringing with them a highly desirable classification.

While this book is addressed primarily to the experimentalist who wishes a rapid survey of basic physical ideas, it should be equally valuable as a supplement, and in some cases as a corrective, to a study of the mathematical apparatus of quantum mechanics. F. C. HOYT